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The British quarterly scientific journal ENDEAVOUR was first published, by Imperial Chemical Industries Limited, in January 1942. Its purpose is to provide scientists, especially those overseas, with news of the progress of the sciences. While emphasis is laid upon British work, occasional articles from overseas contributors are included and impartial reference is made to the world's scientific literature. To make the journal truly international in character it is published in five separate editions—English, French, German, Italian, and Spanish.

No charge is made for ENDEAVOUR. It is distributed to senior scientists, scientific institutions, and libraries throughout the world, the guiding principle being that of helping scientists overseas to maintain those contacts which their British colleagues have always so much valued. Within these limits the Editors are at all times glad to consider the addition of new names to the mailing list.

The drawing on the cover is of the bark Endeavour, *which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in* 1768 *to chart the South Pacific Ocean and observe the transit of Venus*

ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

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Editor: TREVOR I. WILLIAMS, M.A., B.Sc., D.Phil., F.R.I.C.
Editorial Assistant (Foreign Editions): G. N. J. BECK, B.Sc., A.M.I.E.E.

Imperial Chemical Industries Limited, Millbank, London, S.W.1
Communications to the Editor should be addressed to North Block, Thames House, Millbank, London, S.W.1

Robert Hare and the oxyhydrogen blowpipe

The attainment of temperatures high enough to melt metals such as platinum and refractory minerals such as alumina is of very great technical importance. Today it presents no great difficulty, and in the thermonuclear field experiment is being directed, as is described elsewhere in this issue, to the controlled attainment of temperatures of the order of many millions of degrees. It is consequently rather easy to forget the difficulties of the pioneers and the extent of their contribution. In this respect the work of Robert Hare, inventor of the oxyhydrogen blowpipe, is of much interest, and it is appropriate to recall the history of this invention on the occasion of the centenary of Hare's death. His methods were crude by modern standards, but from them have evolved many of the modern methods of cutting and welding metals that are of such great practical importance.

The oxyhydrogen blowpipe was the sole source of high temperatures for industrial use until Langmuir devised his atomic hydrogen blowpipe, shortly after his discovery, in 1911, of atomic hydrogen. This blowpipe was used for platinum working and as a source of heat for the limelight that was used in theatres. It was superseded by electrical heating and by the oxyacetylene blowpipe. The latter had the disadvantage of not providing a protective, non-oxidizing atmosphere of hydrogen, but the ease of working given by its higher temperatures (though these were still only of the order of 4000° C) ensured its success, and its use was widely extended and developed during the first World War.

Hare was by no means the first in the field, for many chemists from Lavoisier onwards had appreciated that intense heat could be generated by burning hydrogen and oxygen together. He was, however, the first to evolve a practical apparatus, though the name of Edward Clarke, professor of mineralogy at Cambridge, is often linked with the discovery.

Hare was only twenty years of age when he made his great invention, demonstrating it at Philadelphia to Joseph Priestley, who had settled in the United States after the unhappy experiences at Birmingham that resulted from his sympathy with the French revolutionaries. It consisted of a double platinum jet with converging ducts; these formed the continuation of two tubes of solid silver, the two jets uniting in a common exit just before the orifice. The hydrogen and the oxygen were derived from the electrolysis of water—hence the original name of 'hydrostatic' blowpipe. For reasons of safety—which, as we shall see later, Clarke ignored to his peril—the gases were contained in separate containers. With this apparatus Hare melted a two-pound block of platinum. This he supported on refractory firebricks in such a way that it could be preheated in a conventional furnace, thus conserving the supply of gas. He noted how in this way crude platinum was 'greatly purified' by the volatilization of some impurities in the metal.

Both Hare and Priestley were members of the Chemical Society of Philadelphia, founded by James Woodhouse in 1792 and the oldest chemical society in the world save one founded by Black's students at Edinburgh in 1785. In 1802 this society published an illustrated memoir describing Hare's invention in detail, and he himself described it in a number of American scientific journals. His work was taken up by, among others, Benjamin Silliman at Yale, founder of the 'American Journal of Science', generally known as 'Silliman's Journal'; but the latter introduced no fundamentally new ideas. In a paper on the 'Fusion of strontites and the volatilisation of platinum' Hare described in full his blowpipe and the apparatus made by Silliman for storing the gases in pneumatic troughs.

At Cambridge, Clarke was appointed to the chair of mineralogy in 1808 and carried out various experiments with oxyhydrogen flames. Unlike Hare, he did not use separate vessels to contain the two gases and in consequence became involved in dangerous explosions: on one occasion he was almost killed. After a copper vessel had burst, endangering the lives of two bystanders, a balloon enclosed in protective planking was used as a container. The first hint of Hare's work seems to have reached Clarke through Newman, a London instrument maker, who in 1816 described in the journal of the Royal Institution a blowpipe using air. Clarke looked upon his blowpipe, using 'a highly condensed mixture of the gaseous constituents of water', as a modification of the Newman apparatus. He later admitted Hare's claim to priority, but seems never to have acknowledged it publicly.

Hare's achievement was recognized by the award of the Rumford medal of the American Academy of Boston, but not until a year before his death in 1858 was the first practical step taken towards making use of the invention for industrial purposes. In 1557 Julius Caesar Scaliger had made the first reference to a South American metal 'which no fire nor any Spanish artifice has yet been able to liquefy'. Exactly three hundred years later, Henri Debray and Henri Ste-Claire Deville announced that they had taken out patents in France, England, and other countries for a platinum-melting technique. They used Hare's oxyhydrogen flame within a small furnace of lime blocks in place of Hare's firebrick refractories. At this time Deville had turned from his brilliant work on aluminium production to the study of the working of such refractory metals as cobalt, chromium, manganese, and platinum. In London the announcement attracted the immediate attention of George Matthey, of the firm of Johnson, Matthey & Co., pre-eminent in the platinum industry. He went immediately to Paris, taking with him some platinum and platinum residues for trial. He found the claims to be justified, and a fruitful collaboration immediately began. In the United States, Joachim Bishop, who had collaborated with Hare in his work on the fusion of platinum, became a founder of the American platinum industry in the firm of Bishop & Co. of Pennsylvania.

The oxyhydrogen blowpipe immediately became a tool of the first importance to chemical engineers, for in platinum apparatus, made possible by Wollaston's perfection of his powder metallurgy technique, it allowed the welding of joints in place of the old gold-soldering. An exhibition of chemical plant staged in London in 1861–62 included a variety of apparatus made by this process as well as a platinum ingot weighing some 450 pounds. Sulphuric acid boilers handling two tons a day of rectified acid were introduced, and these were soon followed by others capable of handling five tons per day. In 1863 Kessler's cascade system for the concentration of sulphuric acid was demanding the manufacture of series of enormous platinum evaporating dishes.

While the blowpipe was Hare's greatest achievement, it ought not to be regarded as by any means his sole claim to fame. His father was English, and had a brewery in Philadelphia; the management of this was his first job, but he soon decided that he wished to make his career in chemistry. Accordingly he joined the Chemical Society of Philadelphia, and doubtless his meeting there with so distinguished a chemist as Priestley was of great help and encouragement to him. He was for nearly forty years, from 1818, professor in the Medical School of the Pennsylvania University, and gained a great reputation both as a lecturer and as a practical man and skilled mechanic. He combined these talents in the construction of apparatus for lecture demonstrations. He carried out many electrochemical experiments, originally using as his source of electricity the same kind of cumbrous troughs, introduced by Cruickshank, as Davy had used in the isolation of sodium and the alkali metals. He soon replaced this by what he called a deflagrator, by means of which any number of zinc-copper couples could at will be brought into action. With this, Silliman succeeded in vaporizing carbon in an arc, and Hare himself used a similar method to fuse platinum. He published an account of the deflagrator as early as 1821 as a 'Memoir on some new modifications of galvanic apparatus', in both the 'Philadelphia Medical Journal' and 'Silliman's Journal', but it attracted little interest. Not until 1835 did it come to the attention of Faraday, then seeking to improve the voltaic battery: he immediately recognized its importance and adopted it.

Hare is also credited with the invention of the first electric furnace, forgotten and re-invented many years later. With it he made calcium carbide, phosphorus, and graphite, all now made industrially in very large quantities in modern electric furnaces. He noted that certain substances, such as lime, which did not fuse in the flame of his blowpipe, glowed very brilliantly when strongly heated. He saw this applied as the Drummond light and in lighthouses. He also introduced the use of a mercury cathode for the electrolysis of solutions of metal salts. Hare corresponded with Faraday, and with Liebig, Berzelius, and other leading chemists of the day.

Like so many others, Hare suffered from living before his proper time. His inventions became of far-reaching importance, and had their exploitation followed close upon their making he would undoubtedly have a far higher reputation as a chemist than is generally accorded to him.

The Darwin–Wallace centenary

SIR GAVIN DE BEER

The collection of facts has always been an essential part of science, but progress depends in the main upon the interpretation of numerous seemingly isolated facts in terms of some general principle. No generalization is of deeper significance than the theory of organic evolution that was announced jointly by Charles Darwin and Alfred Russel Wallace in July 1858. This theory is the fruit of one of the most intensive searches for facts ever carried out and has in all its essentials stood the test of time and is now universally accepted.

FROM SPECIAL CREATION TO TRANSFORMISM

Only one hundred years have gone by since the concept of evolution was brought to the attention of thinking men in a manner which has compelled its acceptance. The demonstration that the members of the plant and animal kingdoms are as they are because they have become what they are, and that change, not immutability, is the rule of living things, is one of the most important contributions ever made to knowledge, and its effects have been felt in every field of human thought.

That plants and animals constitute natural kinds, or species, had become clear by the end of the seventeenth century, when John Ray defined them as groups of individuals that breed among themselves. In general, species were accepted as being the result of special creation in each case, and there was little incentive to inquire further.

In the eighteenth century doubts began to arise concerning the immutability of species. Some philosophers arguing theoretically, and a small number of naturalists who encountered difficulty in distinguishing between varieties of cultivated plants, and of domestic animals, which were recognized as the diversified products of species, found difficulty in accepting the view that species were unchangeable. Some naturalists, including Linnaeus himself in his later years, adopted a compromise, allowing that species could have descended with modification from genera, but that genera were immutable.

With the increase in detailed knowledge of the flora and fauna of the world consequent upon the final stages of exploration, the problem of the distinction between varieties and species became acute. With boldness, and a breadth of vision amounting to genius, the French naturalist Lamarck cut the knot by proclaiming that there was no essential difference between species and varieties, that both species and varieties were subject to change, and that 'transformism', not immutability of species, was the basis of life. As it happened, there were two reasons why Lamarck's ideas were unacceptable. The first was that he undertook no analysis to provide evidence for his notion of evolution: it flashed across his mind, and he assumed its truth without taking the trouble to prove it. Secondly, he attempted to give an explanation of the causes of evolution which, unfortunately, raised opposition to the acceptance of the concept of evolution itself. He supposed that as a result of new needs experienced by the animal, its 'inner feelings' or subconscious activities produced new organs which satisfied those needs. Not only was such a supposition unacceptable for the solution of the problem of the origin of species of animals, but it was totally inapplicable to plants. On the other hand, Lamarck put forward a view which for a long time was accepted but which is now known to be without foundation, namely that the effects of use and disuse were transmitted by inheritance. There for a time the matter rested.

THE FACT OF EVOLUTION

When Darwin started on the voyage of the *Beagle* in 1831, he had no reason to doubt the immutability of species. The speculations of his grandfather Erasmus counted for nothing with him, because they were not supported by evidence. Those of Lamarck on the causes of evolution had the additional demerit of bringing the subject into disrepute by their fanciful nature. It must be added that in Lyell's 'Principles of Geology', to which Darwin owed so much because of the general background of uniformitarianism in place of catastrophism that it advocated, the possibility of evolution was firmly rejected.

Three sets of observations started Darwin's revolt against the immutability of species. The first was occasioned by his studies of the fauna of the Galapagos Islands, where he found that species of finches differed slightly from island to island,

while showing general resemblances not only to each other but to the finches on the adjacent mainland of South America. If these species had been separately created, why should there have been such a prodigal expenditure of 'creation' just there; why should geographical propinquity have caused these 'creations' to resemble each other so closely; why, in spite of the similarity in physical conditions between the islands of the Galapagos Archipelago and the Cape Verde Islands, are their faunas totally different, the former resembling that of South America while the fauna of the latter resembles that of Africa?

The second set of observations related to the fact that as he travelled over South America he noticed that the species occupying a particular niche in some regions were replaced in neighbouring regions by other species that were different, yet closely similar. Why are the rabbit-like animals on the savannahs of La Plata built on the plan of the peculiar South American type of rodent and not on that of North America or the Old World?

The third set of observations was concerned with the fact that in the pampas he found fossil remains of large mammals covered with armour like that of the armadillos now living on that continent. Why were these extinct animals built on the same plan as those now living?

On the view that species were immutable and had not changed since they were severally created, there was no rational answer to any of these questions, which would have had to remain as unfathomable mysteries. On the other hand, if species, like varieties, were subject to modification during descent and to divergence into different lines of descent, all these questions could be satisfactorily and simply answered. The finches of the Galapagos resemble each other and those of South America because they are descended from a common ancestor; they differ from one another because they are each adapted to modes of life restricted to their own particular island, one for instance feeding on seeds on the ground and another on insects in trees. The volcanic nature and physical conditions of the Galapagos Islands resemble those of the Cape Verde Islands, and yet the Galapagos birds all differ from the birds of the Cape Verde Islands: therefore it is not the physical conditions of the islands that determine their differences. These differences arose because the Cape Verde Island birds share a common ancestor with the birds of Africa, whereas the Galapagos birds share a common ancestor with those of South America. The hares of South America are built on the South American rodent plan because all South American rodents are descended from a common ancestor. The fossil *Glyptodon* resembles the living armadillos because they also share a common ancestor; this case is particularly important because, if living species show affinity with extinct species, there is no necessity to believe that extinct types of animals have left no living descendants. They may have representatives alive today, and this means that the whole wealth of the palaeontological record of fossils is available as material for the study of the problem of evolution.

In possession of a working hypothesis that species have undergone evolution and successive origination by descent, with modification, from ancestral species shared in common with other species, Darwin next proceeded to search the whole field of botanical and zoological knowledge for evidence bearing on his hypothesis. He realized that no general principle that explained the evolution of animals was acceptable unless it also applied to plants. The result was one of the most remarkable attacks on a problem ever made by the inductive method of searching for facts, whatever their import might be.

In the first place, in cultivated plants and domestic animals such as the dahlia, the potato, the pigeon, and the rabbit, a large number of varieties have in each case been produced from a single original stock. Descent with modification and divergence into several lines is therefore certainly possible within the species.

Comparative anatomy reveals the existence of similar plans of structure in large groups of organisms. Plants may have vegetative leaves, and in some cases these are modified into parts of flowers. Vertebrate animals have forelimbs that may be used for walking, running, swimming, or flying, but in which the various parts of the skeleton correspond, bone for bone, from the upper arm to the last joints of the fingers, whether the animal is a frog, a lizard, a turtle, a bird, a rabbit, a seal, a bat, or a man. This is what is meant by saying that such structures are homologous, and these correspondences are inexplicable unless the animals are descended from a common ancestor. Fundamental resemblance is therefore evidence of genetic affinity.

The study of comparative behaviour proves that related forms show gradations in their instincts, such as shamming death in insects and nest-building in birds. At the same time, related species inhabiting different parts of the earth under very

different conditions retain similar instincts. Examples are the habit of thrushes in England and in South America of lining nests with mud, and that of wrens in England and North America of the males building 'cock-nests'. Why should this be, unless the different species of thrushes and wrens are descended from common ancestors in each case?

Embryology reveals remarkable similarity in structure between young embryos of animals which in the adult stage are as different as fish, lizard, fowl, and man. This similarity even extends to such details as the manner in which the blood-vessels run from the heart to the dorsal aorta, a plan which is of obvious significance in the case of the fish that breathes by means of gills, but not so obvious in that of lizard, chick, or man, where gill-pouches are formed in the embryo but soon become transformed into different structures, and breathing is carried out by other means. This similarity between embryos is explained by the affinity and descent from a common ancestor of the groups to which they belong.

Embryology also provides evidence of vestiges of structures which once performed important functions in the ancestors but now either perform different functions or none at all. Examples of such organs are the teeth of whalebone whales, the limbs of snakes, the wings of ostriches and penguins, and the flowers of the feather-hyacinth. Since Darwin's time countless other examples have been discovered. The most striking of these are the pineal gland which is a vestigial eye, and vestiges of the egg-tooth still found in marsupials, although it is 75 million years since their ancestors had to use an egg-tooth to crack the shell and hatch out of their eggs. Here again, descent from common ancestral forms explains all these cases.

Knowledge of the fossil record in Darwin's time was so imperfect that nothing was then available in the way of series illustrating the course of evolution. Nevertheless, he noticed that in Tertiary strata, the lower the horizon the fewer fossils there were belonging to species alive today. Palaeontology therefore showed that new species had appeared and old species become extinct, not all at the same time, but in succession and gradually. Why should this be so unless new species have come into existence from time to time by descent with modification from other species?

Plants and animals are classified according to their resemblance, and they are placed in one or other of a not very large number of groups, such as ferns, conifers, molluscs, or mammals. But within each of these groups there is subdivision into other smaller groups, mammals being so subdivided into rodents, carnivores, ungulates, and primates for example. Within these again there is further subdivision, and the important point to notice is that classification always places species in groups that are contained within other larger groups. This is such a commonplace that its significance is often overlooked. Why do organisms have to be classified like this? Why are they not strewn in single file up the ladder of the plant and animal kingdoms, or fortuitously like pebbles on a beach, or arbitrarily like the stars in imaginary constellations? The reason is that the arrangement of groups within groups is a natural classification reflecting the course of evolution. It is the result of descent from common ancestors and an indication of affinity; the differences between the groups are due to modification and divergence during such descent.

Darwin also investigated the problem of interspecific sterility and saw that it was by no means absolute, because numerous examples can be found of different species that produce hybrids, and in some cases these hybrids are themselves fertile. From the point of view of breeding, therefore, such species behave like varieties. Why, then, can species not have originated as varieties, by descent and modification from other species?

From the evidence provided by all these sources Darwin built up an irrefutable argument that species have changed and originated from other species and that evolution has occurred. That he should have been able to do so from such few data is a mark of genius, for at the time when he worked out his conclusions, none of the cases had been discovered which would now be used as the most striking examples with which to illustrate the fact and the course of evolution. Chief among these are the beautiful series of fossils which reveal the evolution of the ammonites or of the horses, step by step, and those which represent the precursors of the various classes and groups of vertebrates such as *Archaeopteryx* or *Pithecanthropus*.

The main steps in Darwin's proof of the fact of evolution were established by 1842, when he committed them to paper in the form of a Sketch which he expanded into an Essay in 1844, though neither was published by him. Soon after this, another naturalist, Alfred Russel Wallace, was led to explore similar lines of research. From some simple observations on the distribution of organisms, both geographically over the world and geologically in the fossil record, Wallace drew some equally simple conclusions that are of great

importance in the history of thought that led to the realization of evolution. They show that, independently of Darwin and in complete ignorance of his work, Wallace had hit upon the same solution of the problem of the mutability of species.

Wallace's observations were based on the facts, firstly, that large systematic groups such as classes and orders are usually distributed over the whole of the earth, whereas groups of low systematic value such as families, genera, and species frequently have a very small localized distribution. Secondly, 'when a group is confined to one district, and is rich in species, it is almost invariably the case that the most closely allied species are found in the same locality or in closely adjoining localities, and that therefore the natural sequence of the species by affinity is also geographical.' Thirdly, in the fossil record large groups extend through several geological formations, and 'no group or species has come into existence twice.'

The conclusion which Wallace drew from these observations was that 'Every species has come into existence coincident both in space and time with a pre-existing closely allied species.' Thought out about 1845, written at Sarawak in 1855, and published in the same year, Wallace's theory already allowed him to say that 'the natural series of affinities will also represent the order in which the several species came into existence, each one having had for its immediate antitype a closely allied species existing at the time of its origin. It is evidently possible that two or three distinct species may have had a common antitype, and that each of these may again have become the antitype from which other closely allied species were created.'

With the help of this principle, in which it is only necessary to substitute 'ancestor' for 'antitype' for the formulation of evolution to be complete, Wallace showed that it was possible to give a simple explanation of natural classification, of the geographical distribution of plants and animals, including those of the Galapagos Islands, of the succession of forms in the fossil record, and of rudimentary organs which would be inexplicable 'if each species had been created independently, and without any necessary relations with pre-existing species.'

So much of the credit for the establishment of the fact of evolution has, rightly, been accorded to Darwin that it is only just that Wallace's contribution to this problem should be recognized and honoured.

The evidence on which Darwin and Wallace based their demonstration that evolution was a fact is not only valid to this day, but has been confirmed in all the branches of science concerned as well as in many new fields. There was in their day not even an inkling of the possibilities of research opened up by comparative physiology and biochemistry, or of serology as a quantitative indicator of the amount of divergence that has taken place between related forms. Why should the chemical substance involved in the mechanism of muscular contraction in most invertebrates be arginine, whereas it is creatine in vertebrates and echinoderms, which on independent evidence are regarded as related? Why should serum immunized against man give precipitations of 64 per cent when mixed with blood of a gorilla, but 42 per cent with that of an orang utan, 29 per cent with that of a baboon, and only 10 per cent with that of an ox? Why should syphilis attack the chimpanzee more seriously than the orang-utan, and the latter more seriously than the baboon? Why should the human ABO blood group system also be found in the apes? The answer to all these questions is that the organisms concerned have undergone evolution from common ancestors, as a result of which members of the various lines of descent share not only structural, mental, and genetical characters, but also physiological and biochemical mechanisms and immunological reactions.

THE MECHANISM OF NATURAL SELECTION

Although Darwin already knew in 1837 that evolution was an inescapable conclusion to be drawn from the evidence, he did not allow himself to proceed any further with his discovery until he had found an explanation of the fact of adaptation. In a general way, all plants and animals are adapted to their environment, for otherwise they could not live. A man drowns in the sea; a fish dies out of water. But there are some structures which show a particularly intimate relationship between the organism and its conditions of life. Mistletoe is a parasite that requires a tree of certain species to live on, a particular insect to pollinate its flowers, and a thrush to eat its berries and deposit its seeds on branches of the same species of tree. A woodpecker has two of its toes turned backwards with which it grips the bark of a tree; it has stiff tail-feathers with which it props itself against the tree; it has a very stout beak with which it bores holes in the tree trunk; and it has an abnormally long tongue with which it takes the

grubs at the bottom of the holes. Other plants than mistletoe and other birds than woodpeckers do not have all these adaptations, and therefore, if evolution has occurred, it is necessary to give an objective explanation of how these adaptations arose.

Darwin knew that all members of a species are not identical but show variation in size, strength, health, fertility, longevity, instincts, habits, mental attributes, and countless other characters. He soon perceived that such variation could be, and in fact was, turned to good account by man in the course of artificial selection, which he has practised in the production of cultivated plants and domestic animals since the New Stone Age. The key was selection, the practice of breeding only from those parents that possess the desired qualities. But how could selection have operated on wild plants and animals in nature since the beginning of life on earth without man or a conscious being to direct it? The solution of this puzzle occurred to Darwin accidentally when he read Malthus's 'Essay on Population' and realized that under the conditions of competition in which plants and animals live, any variations would be preserved which increased the organisms' ability to leave fertile offspring, while those variations which decreased it would be eliminated. In a state of nature, selection works automatically, which is why Darwin called it Natural Selection.

Darwin was then able to formulate a complete theory providing a rational explanation of the causes as well as of the fact of evolution in plants and animals. It is formally based on four propositions which he already knew to be true, and three deductions which are now also known to be true. They may be enumerated as follows.

1. Organisms produce a far greater number of reproductive cells than ever give rise to mature individuals.
2. The numbers of individuals in species remain more or less constant.
3. Therefore there must be a high rate of mortality.
4. The individuals in a species are not all identical, but show variation in all characters.
5. Therefore some variants will succeed better and others less well in the competition for survival, and the parents of the next generation will be naturally selected from among those members of the species that show variation in the direction of more effective adaptation to the conditions of their environment.
6. Hereditary resemblance between parent and offspring is a fact.
7. Therefore subsequent generations will by gradual change maintain and improve on the degree of adaptation realized by their parents.

This is the formal theory of evolution by natural selection, first announced jointly on 1st July 1858 by Darwin and Alfred Russel Wallace, who had, again independently, come to the identical conclusion. It represents a step in knowledge comparable to Newton's discovery of the law of gravitation.

THE INTEGRATION OF MENDELIAN GENETICS WITH SELECTION

When Darwin wrote, nothing whatever was known about the laws of heredity, and all that he had to go upon was the vague notion that offspring tended to strike an average between the characters of their parents. This supposition went by the name of 'blending inheritance', and it occasioned for Darwin the greatest difficulty with which he had to contend in formulating his theory. In the first place, if blending inheritance were true, it would mean that any new variation which appeared, even if heritable, would be rapidly diluted by 'swamping', and in about ten generations would have been obliterated. To compensate for this it would be necessary to suppose that new variations were extremely frequent. Since whole brothers, sons of the same father and mother, share an identical heredity, any difference between them would have to be due to new variation that had arisen during their own early lives, and variation would have to affect practically all members of a species. This problem of the supply of variation was a difficulty which Darwin felt so acutely that it even led him to look for a source of this supply in the supposed hereditary effects of use and disuse.

This reliance on the effects of use and disuse as a source of variation, without any effect on his main argument, is the only part of Darwin's demonstration that has had to be abandoned, and he would have welcomed the reasons for it. If only Darwin had realized it, the solution to all these difficulties was at that very time being provided by Gregor Mendel, but his results remained unknown until 1900, eighteen years after Darwin's death.

The Mendelian theory of the gene was worked out by T. H. Morgan and his colleagues with an unprecedented wealth of experimental evidence

from the breeding pen and from cytological studies on the structure of the cell and its chromosomes. It has established, as firmly as Newton's laws of motion or the atomic theory, that hereditary resemblances are determined by discrete particles, the genes, situated in the chromosomes of the cells, which are transmitted to offspring in accordance with the mechanism of germ-cell formation and fertilization, and conform to distributional patterns known as Mendelian inheritance. The researches of C. D. Darlington and others on the structure and behaviour of the chromosomes have reached such a degree of refinement and precision that each step in the mechanism of Mendelian inheritance can actually be seen under the microscope.

The genes preserve their separate identity; they collaborate in the production of the characters of the individual that possesses them, but they never contaminate each other; they remain constant for long periods, but from time to time they undergo a change, known as mutation, which involves a change in the characters which they control; after this they remain constant in their new condition until they mutate again. It has been conclusively proved that the theory of the gene applies to all plants and all animals investigated, and that the mutation of genes is the only known way in which heritable variation arises. The modifications resulting from good or bad food supply, or from the climatic conditions in which plants and animals live, are not inherited and are therefore without significance in evolution.

The history of the reception of Mendelian genetics after its discovery has been peculiar. The earliest mutations discovered, often called 'sports', were usually deleterious and showed marked and discontinuous steps instead of the gradual and continuous variation which Darwinian selectionists looked for as the raw material of evolution. Selectionists therefore rejected Mendelian genetics as the source of variation. On the other hand, the Mendelian geneticists, knowing that their mutations were the only source of heritable variation, thought that as they showed wide discontinuous steps and arose suddenly, ready-made and apparently without long-continued selection, selection was inoperative in evolution, and they rejected it.

With the progress of knowledge it gradually became obvious that each of these two schools of research objected to the other for reasons which were baseless. As more and more genes were identified and their effects studied, it became clear that the wide and discontinuous mutations first observed were the more easily detected extremes of a range in which the majority exert only slight effects. For the same reason, these mutations were deleterious because organisms are delicately adjusted systems, more likely to be upset by large and discontinuous changes than by small and gradual steps.

The Mendelian geneticists also had to learn two lessons. On the one hand they discovered that although individual genes are associated with particular characters, their control of those characters is also affected by all the other genes, which constitute an organized gene-complex. As a result of previous mutations, gene-complexes of plants and animals in nature contain many genes, and these are sorted out and recombined at fertilization in astronomically numerous possibilities of permutations. These recombinations have been shown to bring about gradual and continuous changes in the characters under the major control of individual genes. Sir Ronald Fisher demonstrated the significance of this by showing that a mutant gene that now exhibits the quality known as dominance has gradually become dominant from a previous intermediate condition. This is what has happened to those mutations that confer a benefit on their possessors, and in their case there has been a selection of gene-complexes in favour of those which accentuate the effects of a favourable mutant, so that these effects are manifested even if the mutant gene is inherited from only one parent, which is the definition of dominance. Conversely, with genes that place a handicap on their possessors, there has been a selection of gene-complexes in favour of those which suppress the effects of such genes so that they are manifested only when the mutant gene is inherited from both parents, which is the definition of recessiveness. They may be suppressed even further, as when the effects of such a gene are obliterated and the gene becomes what is known as a 'modifier', without major control over characters. It has even been demonstrated by E. B. Ford, under rigorous experimental conditions, that one and the same mutant gene can be made to become dominant in one strain and recessive in another, simply by selecting as parents those individuals whose gene-complexes accentuate or diminish the effects of the gene.

The second lesson that Mendelian geneticists had to learn was that although the effects of the mutations which they first observed appeared to be clear-cut, they were already the results of past

gene-complexes. For these mutations have occurred before, and the gene-complexes have become adjusted to them. The fact that a single gene may now act as a switch controlling the production of one or other character-difference does not mean that this character-difference originally arose at one stroke by one mutation of such a switch-gene, because it has probably been built up gradually as a result of past selection in the gene-complex.

It is therefore clear that mutations and recombinations of genes provide the supply of variation on which selection acts to cause evolution exactly in the way Darwin's theory requires. Its requirements are exacting, for, as T. H. Huxley pointed out, some organisms have evolved slowly and others have evolved fast; he saw that natural selection was the only mechanism that could satisfy both those requirements. It is able to do so because Mendelian inheritance is capable of producing both diversity and stability. As Ford has said, an immense range of types must be available for natural selection to act upon, and this is provided by mutation and recombination of genes. Yet when a favourable gene-complex has been achieved it must not be dissipated and broken down, and this is provided against by the facts that the genes do not blend or contaminate one another, and that they mutate only rarely.

THE SIGNIFICANCE OF PARTICULATE INHERITANCE IN EVOLUTION

The particulate theory of inheritance which Mendelian genetics has established involves a number of consequences of fundamental importance for the problem of evolution. In the first place, the substitution of this quantitative and deterministic science for the vague and baseless notion of 'blending inheritance' completely disposes of the difficulty under which Darwin laboured to account for the necessary supply of variation on which natural selection could act. The most characteristic feature of the Mendelian gene is that it never blends, but retains its identity and properties intact for long periods of time until it mutates, after which it remains intact in its new condition until it eventually mutates again. This means that the amount of variation, or variance, present in a population resulting from previous mutations, is not only conserved through generation after generation, but is actually increased as a result of the recombinations of the gene-complexes in their innumerable possible permutations. This power of increase is one of the most important results of the bi-parental method of reproduction and is the reason why organisms possessed of this mechanism have evolved further than those that lack it.

This conservation of variance is to be considered in relation to the rate at which mutation normally occurs. It has been calculated that in organisms as diverse as a bacterium, a maize-plant, a fruit-fly, and in man, any given gene mutates in one in about half a million individuals. It is also clear that this rate is itself the result of selection, and that although seemingly slow, it has been adequate to provide the requisite basic heritable variation which the mechanism of germ-cell formation and fertilization has multiplied, and on which selection has worked to produce whatever evolution has taken place. In other words, mutation not only need not, but must not be more rapid than a slow rate. This rate is ten thousand times slower than what it would have to be if 'blending inheritance' were a fact, and Darwin's difficulty in accounting for an adequate supply of variation is lightened by that amount.

As the originating mechanism for basic heritable variation, mutation has naturally been intensively studied. It has been found that certain physical and chemical agents, including radioactivity, can accelerate the rate at which mutation would naturally occur, but that these induced mutations are similar to those which occur and recur normally, and no correlation whatever exists between the mutagenic agents and the quality or 'direction' of the mutations. Mutations take place with 'blindness and molar indeterminacy', as H. J. Muller has expressed it. This is a finding of capital importance, for it shows that there is no basis for attempts to explain the origin of heritable variation by appealing to environmental factors to evoke appropriate responses, or to the internal factors to make such responses. Nor is there any basis for the view that the environment would evoke appropriate heritable responses if its actions were continued for a sufficient time, because, as J. B. S. Haldane showed, such responses as might be significant in evolution would be detected within the period of the experiment carried out.

In organisms that reproduce by simple division of the whole body, such as bacteria, special conditions apply because reproduction in them involves not only transmission of genetic material in the form of genes, but also transmission of bodily characters, since the latter are carried over wholesale from 'parent' to offspring. Adaptation to new environments can take place in bacteria. Furthermore,

in bacteria, and perhaps also in higher organisms, it is possible for organic molecules such as bacteriophage particles to enter organisms and become incorporated in the genetic mechanisms so as to behave like genes. These results are full of promise as a field of research into the nature of genes, and perhaps of mutations, but they do not in any way invalidate the principles of Mendelian genetics and inheritance.

Mutations are chemical changes in the gene-molecule, and since chemical stability is not absolute, the puzzle about mutations is not so much that they occur as that they occur so infrequently. This ignorance of the causes which determine the directions in which mutations take place, if such causes indeed exist, is, strange to relate, no handicap to the understanding of the mechanism of evolution, because it is emphatically selection, not mutation, that determines the direction of evolution. This all-important conclusion is based not only on detailed experimental studies on the effects of selection in nature, but also on the demonstration by Sir Ronald Fisher of a general principle. The effects of selection in changing the frequency of genes in a population have been calculated for various percentage benefits in survival-value conferred by such genes. It has been found by calculation that at the observed natural average mutation-rate of one in half a million, no mutant gene has the slightest chance of maintaining itself against even the faintest degree of adverse selection. Furthermore, if the direction of evolution were determined by the direction of mutation, it would be necessary to suppose that such mutations must be predominantly favourable. In fact, the vast majority of mutations have been unfavourable, and natural selection has acted against them by converting the resulting mutant genes into recessives, or by suppressing them into the condition of mere modifiers, or by exacting the more drastic price of abolition consequent on the rapid death of the organisms containing them. It is natural selection, not mutation, that has governed the direction as well as the amount of evolution, and it has been estimated that if mutation were to stop now, there is already sufficient variation in the plant and animal kingdoms for evolution to continue for as long in the future as it has continued hitherto in the past.

The bearing of this demonstration on hypotheses that attempt to explain evolution by postulating the existence of agencies capable of directing mutation is plain. It means that all such theories as invoke the effects of use and disuse, 'inheritance of acquired characters', environmental stimuli, 'organic selection', 'inner feelings', 'inherited memory', momentum along particular directions, orthogenesis, nomogenesis, and others, which assume that mutation can be made to follow adaptively desirable directions, are not only devoid of any known mechanism by which the direction of mutation might be brought about, and devoid of evidence for the existence of such mechanisms, but they involve a cause 'which demonstrably would not work even if it were known to exist'. It is therefore not surprising that in spite of repeated attempts, many undertaken with impure and insufficiently standardized genetic material, and others in which the results were simply faked, no evidence has been provided that the effects of use and disuse or adaptive response to environmental conditions are inherited or induce appropriate mutations. From the evidence provided by genetics, natural selection is the only mechanism capable of explaining evolution.

NATURAL SELECTION, 'IMPROBABILITY' AND 'CHANCE'

An argument sometimes used against the efficacy of natural selection involves the claim that the initial stages in the evolution of complex structures or functions could not have been favoured by natural selection until such structures or functions had reached a certain level of perfection. Like all other arguments of the *non possumus* type, this one melts away before the progress of knowledge. A case in point is that of the electric organs of fish, developed out of muscles which are capable of discharges strong enough to catch prey and defend the fish against its enemies. These organs are clearly adaptive and confer survival-value on their possessors, but the question arises what functions they could perform in the initial stages of their evolution, when it must be supposed that their power was too weak to kill prey or to deter predators. Darwin himself was well aware of this problem, and he met the argument by pointing out that 'it would be extremely bold to maintain that no serviceable transitions are possible by which these organs might have been gradually developed'. He has been proved to be right, because of the discovery by H. W. Lissmann that weak electric discharges given off by certain fish function in a manner analogous to those of radar equipment, and serve to convey information of the proximity of objects in the water. Electric organs can therefore be adaptive even when they are too weak to kill prey or deter predators.

Another case may be cited because it illustrates the manner in which an adaptive result may be achieved without itself being a direct object of selection. Colour vision has been evolved independently in many groups of animals. Among the light-sensitive elements in the eye, some are specially sensitive in dim illumination; others confer acuteness of vision in bright light when they are individually innervated, with the result that light-stimuli are perceived separately by very small areas of the retina. In each of the two functions of seeing in relative darkness and seeing accurately in the light, increased efficiency confers survival-value from the very start of the improvement. But when both these functions have been achieved in the same eye a mechanism is produced, as E. N. Willmer has indicated, in which the visual elements are differentially sensitive to light of different wavelengths, and this is the basis of colour vision. The emergence of colour vision as an unexpected 'bonus' resulting from the perfection of two other functions is a concrete example of the principle to which Lloyd Morgan applied the term 'emergent evolution'.

It has also been objected that natural selection is a difficult concept to apply to the evolution of very complex adaptations involving co-ordinated variations either in one and the same organism, or even in two different organisms. It is not necessary to go far afield to find examples of this, for in all animals with separate sexes and internal fertilization there has been a separate yet harmonious evolution of the reproductive organs in the two sexes. It has been supposed that such situations argued so high a degree of 'mathematical improbability' that they could not be explained as a result of natural selection, which was, very erroneously, called 'chance'. To this objection there are several answers.

In the first place, those who invoke mathematical improbability against natural selection can be refuted out of their own mouths. Muller has estimated that on the existing knowledge of the percentage of mutations that are beneficial, and a reasoned estimate of the number of mutations that would be necessary to convert an amoeba into a horse, based on the average magnitude of the effects of mutations, the number of mutations required on the basis of chance alone, if there were no natural selection, would be of the order of one thousand raised to the power of one million. This impossible and meaningless figure serves to illustrate the power of natural selection in collecting favourable mutations and minimizing waste of variation, for horses do exist and they have evolved.

It is worth while to study the question of improbability more closely. As Fisher has pointed out, improbability has a different aspect when considered from time before or time after the event. The probability that any man alive today will have sons, grandsons, and successive descendants in the male line uninterruptedly for one hundred generations is infinitesimally small. Yet every man today is the living proof that this contingency, so highly improbable as it may have seemed one hundred generations ago, has nevertheless occurred. Similarly, the effects of natural selection are the reverse of chance when considered *ex post facto*; they are rigorously determined, and what they have done is to channel random variation into adaptive directions and thereby simulate the appearance of purposive change. This is why natural selection has been paradoxically defined as 'a mechanism for generating an exceedingly high degree of improbability'.

Mention of purpose introduces the notion of teleology or fulfilment of design which has sometimes been invoked to explain the production of complex adaptations. Teleology and providential guidance are double-edged weapons with which to attack the problem of evolution, because it can be shown that the more detailed the adaptation, the more 'improbable' it may appear as a product of 'chance', the more likely its possessor is to be doomed to extinction through inability to become adapted to changed conditions.

Structures may be developed which at first benefit individuals in their competition to survive; but by continued selection such structures may become exaggerated and lead to the extinction of the species. This seems to have been what happened to the Huia-bird, where mated pairs constantly remained in company together, and the beaks of the male and female reached an extraordinary disparity of size in adaptation to their very special feeding, but failed to enable the birds to obtain ordinary food when their special diet was unavailable. Excess, even of adaptation, is harmful, and the fossil record shows that the vast majority of lines of evolution have led to extinction, which is a grim comment on the alleged powers of providential guidance and purpose.

From the undoubted fact that many of the products of the plant and animal kingdom convey to man the aesthetic quality of beauty, it has been supposed that beauty is an end in itself to which the criterion of usefulness and survival-value could

not be applied, and therefore that it could not be imagined as a product of evolution. To this argument Wallace opposed the demonstration that if the quality of beauty were an exception to the principle of evolution by natural selection, it would be necessary to find an explanation for the existence of so much in plants and animals that is positively ugly.

Darwin showed it to be an invariable rule that 'When a flower is fertilised by the wind it never has a gaily-coloured corolla'. The beauty of flowers has been gradually achieved because of the survival-value of cross-fertilization (consequent upon the attraction of insects to such flowers) conferred on plants possessing them. The beautiful colours and structures of birds and some other animals have resulted from the survival-value conferred on successful competitors in sexual selection.

This demonstration of what may be called the natural nature of beauty has been developed still further by Ray Lankester in the course of a soliloquy on alpine flowers: 'All beauty of living things, it seems, is due to Nature's selection, and not only all beauty of colour and form, but that beauty of behaviour and excellence of inner quality which we call "goodness". The fittest, that which has survived and will survive in the struggle of organic growth, is, (we see it in these flowers) in man's estimation the beautiful. Is it possible to doubt that just as we approve and delightedly revel in the beauty created by "natural selection", so we give our admiration and reverence, without question, to "goodness", which also is the creation of Nature's great unfolding?'

In many of the higher animals, parental care and self-sacrifice, in the interest of other members of the family such as incubating or gravid females and young, have been favoured by natural selection and conferred benefit on the species. From earliest human times, the survival-value of altruistic behaviour has been enhanced because of the prolongation of childhood and the consolidation of the family that have characterized the evolution of man. The size of the unit within which altruistic behaviour conferred survival-value has grown progressively larger, but fitfully, as history and anthropology have shown, from the family to the clan, the tribe, and the nation. In this manner, ethical standards of conduct and morality have arisen which can be seen to develop in individuals and have been seen to evolve in societies. Between these units, competition on the subhuman level of natural selection has persisted. With the development of man's higher mental faculties, conscious choice and purposiveness became factors in evolution, and for this reason the subsequent evolution of man has been of a nature different from that of other organisms because it was no longer governed solely by natural selection.

NATURAL SELECTION IN ACTION

Natural selection can be seen to be at work here and now in directing evolution. Modern techniques of study of genetics in populations in the field developed by T. Dobzhansky and E. B. Ford have shown that the relative longevities of variants in different environments can be directly measured, and that the effects of such differential mortality have been to produce evolutionary change. An example of this type of research is that of H. B. D. Kettlewell on 'industrial melanism' in moths (figure 1). Up to 1850 the British peppered moth existed in its typical grey form known as *Biston betularia*, which is remarkably well adapted to resemble the lichens on the bark of trees. From that date a dark melanic variety appeared, known as *carbonaria*, which is extremely conspicuous against the natural bark of trees. The melanic variation is controlled by a single dominant Mendelian gene and is slightly more vigorous than the normal grey type. Nevertheless, because of its conspicuous colour the *carbonaria* variety was constantly eliminated, and this variety persisted in the populations of the peppered moth only because the same mutation kept on occurring again and again. The Industrial Revolution brought about a marked change in the environment, since the pollution of the air by increasing quantities of carbon dust killed the lichens on the trees and rendered their trunks and branches black. Under these conditions it is the *carbonaria* variety which is favoured and the *betularia* penalized. This has been proved by direct observation of the feeding of birds, and by measurement of the survival-rates of the different forms in the different environments. The dark *carbonaria* form survives 17 per cent less well in an unpolluted area and 10 per cent better in a polluted area. One hundred years ago the dark variety of the peppered moth formed less than 1 per cent of the population; today in industrial areas it forms 99 per cent, and selection has made it more intensively black than when it first appeared.

The case of melanism in the peppered moth also introduces a principle to which L. Cuénot drew attention and gave the name of 'pre-adaptation'. The melanic form of the peppered moth happened to be 'pre-adapted' to conditions which were only

subsequently realized, or in other words, if the Industrial Revolution had not taken place, the melanic variety would never have become adaptive at all, and would have suffered the same fate as the countless other mutations resulting in variations which, whether 'pre-adapted' or not, have been eliminated because they fell short of the requirements imposed by natural selection.

The evolutionary change actually witnessed in the peppered moth is directly attributable to selection, and it is matched by similar studies on other forms. Experiments by A. J. Cain and P. M. Sheppard on the survival-rate of snails with shells of different colours and banding patterns, living on dark- or light-coloured backgrounds, have shown that selection does not act like an all-obliterating steam-roller going in one direction. As the seasons change, the adaptive value of the colour of a shell changes from disadvantageous to advantageous and back again. This proves that the effects of selection vary from place to place and from season to season, and that the balance between an organism and its environment is delicate, changing, and dynamic.

The phenomenon of Batesian mimicry has also been proved not only to be adaptive and to confer survival-value, but to have been achieved by selection. Ford has shown that the degree of perfection with which the mimics copy their models is a function of the prevalence of the models. The percentage of imperfect mimics in the populations of *Papilio dardanus* is only 4 at places like Entebbe, where models are numerous. At Nairobi, on the other hand, where the models are 70 times less numerous than at Entebbe, the imperfect mimics are 8 times more numerous and constitute 32 per cent of the population. Less survival-value is conferred by resemblance to a model when the latter is too infrequent to teach predators to shun it, and there is then less selection-pressure on the mimic to resemble it.

While the overriding importance of the effects of selection is now generally realized, it has been suggested that when populations are split up into very small isolated colonies, changes in the relative frequencies of different genes might result from the errors of random sampling in the formation of the germ-cells and their fertilization, without involving selection. This concept, advanced by Sewall Wright and known as 'random genetic drift', has been invoked as a possible cause of non-selective, non-adaptive evolution. It has, however, been invalidated by the results of experimental studies in the field such as those of Fisher and Ford on moths, which have shown that selective factors are much more important than casual non-adaptive factors in determining the relative frequency of genes and in bringing about close adaptation to local environmental conditions. Even in comparatively numerous populations, from one generation to the next there are fluctuations in gene-ratio larger than can be attributed to random sampling and which are controlled by selection. Such effects as may be due to random sampling in small populations can only be of negligible significance in evolution.

Selection frequently works on a basis of compromise. Among the natives of Africa there is a condition known as sickle-cell anaemia, in which the red blood-corpuscles are deformed and shaped like the blades of sickles. This is controlled by a Mendelian gene which, when inherited from both parents (homozygous), produces an extreme effect which frequently kills the subject by thrombosis. When inherited from only one parent (heterozygous), the danger from thrombosis is not so great. In areas where malaria is present, however, there is a positive advantage in possessing the sickle-cell gene, because the malaria parasite cannot enter the sickle-shaped red blood-corpuscles. In accordance with the prevalence of malaria in the environment, therefore, a balance is automatically struck in the population between the danger of dying from malaria if the individual has no sickle-cell gene, and the danger of dying of thrombosis if the individual has two sickle-cell genes. Survival-value and ability to leave more offspring therefore accrues to the possessors of one sickle-cell gene up to a certain frequency, and this example shows in what unexpected ways selection is able to make the best even of a bad gene-complex.

NATURAL SELECTION AND PALAEONTOLOGY

The palaeontological record provides the evidence of the course which evolution has followed in the past. The fossil material is in places now so rich that it can be used for quantitative studies in evolution. Firstly, the radioactive time-clocks enable various levels of evolutionary lineage to be dated and the time measured during which certain changes have occurred. This provides quantitative evidence of evolution rates. From such data estimates can be obtained of the duration-times of genera and species. Statistical study of large samples of fossil materials enables the variability of the different species to be assessed. By methods

such as these, G. G. Simpson has worked out that the evolution from *Hyracotherium* to *Equus* occupied 60 million years. This involved passage through 8 genera, the duration of each being on the average 7·5 million years; 30 species of a duration-time of 2 million years each; and 15 million generations each reaching maturity in 4 years. These data can be compared with those obtained from other groups of animals, from which they differ considerably. The results show that evolution rate is not correlated with variability, nor with generation-time, and that it is selection that controls the direction and intensity of evolution.

These results are all the more important because in the past some palaeontologists, unequipped with knowledge of modern genetics, have imagined that from tracing the course of evolution in the lineage of fossils which they established they were in a position to draw conclusions about the cause of such evolution. Some have thought that they had found support for the inheritance of acquired characters, although they knew nothing about inheritance; others imagined that as the lineage of some fossils showed linear progression of certain characters, they were justified in concluding that evolution involved an innate directional component, an expression of 'momentum' leading to evolution in 'straight lines', which they called orthogenesis. They failed to realize that if selection in a particular direction benefits an organism, continued selection in the same direction will, up to a certain point, benefit it further. Others again have concluded from their materials that a distinction in principle could be made out between 'big' evolution leading to large evolutionary changes, and 'small' evolution producing trifling results. None of these speculations can stand up to the evidence that selection determines the course of evolution, its speed or its slowness, the greatness or smallness of the effects produced, and its direction, which if constant for any length of time simulates orthogenesis.

It is of interest to consider how far it is possible to extrapolate the results of modern genetics into the palaeontological past. C. R. Diver has shown that, in snails, the patterns of banding found today were already in existence in Pleistocene times. It is necessary, however, to beware of concluding that because characters are similar they must be controlled by the same genes. Even in one and the same species today, the gene-complex can undergo permutations which reproduce the same structures with different genes. An example is provided by the gene 'eyeless' in *Drosophila* which produces flies with very small or no eyes; this is, of course, extremely harmful. Eyeless flies can, however, be made to breed, and although the mortality is very high, progeny can be reared which after a few generations have eyes like normal flies. In such a stock the 'eyeless' gene is nevertheless present unaltered, as can be proved by mating these flies with normal flies, when the effects of the 'eyeless' gene manifest themselves in all their force, though in the second generation, because 'eyeless' is recessive. This result is therefore in perfect accordance with the principle that Mendelian genes do not become contaminated. What has happened during the inbreeding of 'eyeless' flies is that the reshuffling of the other genes has produced a gene-complex in which the harmful effects of 'eyeless' have been suppressed.

The gene-complex is therefore a dynamic system, as S. C. Harland concluded from his researches on cotton. Genes compete, i.e. are selected in the gene-complex, old genes being dropped and new genes incorporated. During the course of evolution the effective membership of the gene-complex must have changed, and it is not legitimate to conclude that because a character or a structure like the eye of vertebrates was in existence 400 million years ago, it was then controlled by the same genes as control it now. The evidence is entirely opposed to such a static view. It is precisely because the gene-complexes change that characters, structures, and organisms have evolved.

THE NEW SYSTEMATICS AND THE ORIGIN OF SPECIES

The researches on industrial melanism in the peppered moth, banding and colour of snails, mimicry in butterflies, local adaptation in moths, and sickle-cell in man, which have here been briefly described, are examples of new techniques of experimental study of evolution in the field. They have grown out of what Julian Huxley has aptly called 'The New Systematics', to which he has himself contributed so much. Systematics, the study of species and of the higher groups of classification, began by the recognition of differences between species, defined from type specimens preserved in museums. But with the realization that species now or in the past are or were populations of live plants and animals in nature, living under varying conditions of equilibrium with each other and with the inorganic factors of the environments —themselves showing geographical variation in space, and undergoing variation in time, subject to mutation and recombination of their genes,

FIGURE 1 – *Natural selection in action. Left: Photograph of a tree-trunk from the West of England covered with lichen on which are one typical light-coloured peppered moth (below), and one specimen of the melanic variety* carbonaria *(above). Under these conditions the melanic variety has been observed to fall victim to predatory attacks by birds to a greater extent (17 per cent) than the light-coloured variety. Right: Photograph of a tree-trunk from an industrial region, devoid of lichen and covered with deposits of soot on which are one typical light-coloured peppered moth (above) and one specimen of the melanic* carbonaria *variety (below). Under these conditions the melanic variety has been observed to fall victim to predatory attacks by birds to a lesser extent (10 per cent) than the light-coloured typical form. The melanic variety appeared 100 years ago, and in industrial areas of Great Britain it now forms 99 per cent of the populations of the peppered moth. (From exhibits in the British Museum (Natural History), prepared with the assistance of H. B. D. Kettlewell.)*

constantly under the influence of selection—species can no longer be considered as static milestones of evolution, for they are themselves the dynamic systems by which the roads of evolution are trodden. As genes mutate and are reshuffled, and geographical races invade new ecological niches, advance and retreat, it is already possible on a map to mark out lines of gene-flow, as R. C. Stebbins has suggested from his researches on Californian newts. It may become possible to plot the areas of gene-complex alteration, as can to a certain extent already be done for the origin of cultivated plants such as wheat; but such maps will be continually changing, like the species themselves.

Nobody would have welcomed these developments of biological science more than Darwin himself, as a glance at the last few pages of 'The Origin of Species' will show. It is therefore appropriate to return to the problem with which this article began. As is now certain, species are not immutable but have undergone change, and many examples have been given above. Evolution can take place up to a point without the production of new species, but if this process continues the time must come when new species originate, and it is legitimate to ask whether modern research has revealed any evidence of this. The answer is that new species can be seen originating in nature here and now, and new species have been artificially produced in the laboratory.

FIGURE 2 – *Geographical species-formation. The British lesser black-backed gull with its dull mantle and its yellow legs grades into the Scandinavian lesser black-backed gull, and it in its turn grades into the Siberian Vega gull with its lighter mantle and its dull flesh-coloured legs. The Siberian Vega gull grades into the American herring gull, which in turn grades into the British herring gull with lighter mantle and pinkish legs. Although the British lesser black-backed gull may be regarded as belonging to the same species as all the other gulls in the chain to the east of it, when it is compared with the other end of the chain represented by the British herring gull, the two may almost be regarded as separate species. They differ not only in colour but in habits, for the former breeds on moors and is migratory in winter, while the latter nests on cliffs and is dispersive. If at any time the chain becomes severed by local extinction of the gull population or the erection of a sterility barrier, the two British gulls will have become separate species. (From exhibits in the British Museum (Natural History).)*

Speciation takes place when, for various reasons, populations cease to breed with neighbouring populations and, under different conditions of selection, accumulate heritable variations by mutation and recombination of genes in different directions. As E. Mayr has shown, some form of biological isolation between portions of populations is a necessary condition for divergence leading to the formation of new species and higher groups.

Among the kinds of isolation that are chiefly responsible for the origination of species, geographical isolation is the most important; it involves physical barriers such as oceans, mountain ranges, or deserts which separate whole populations. Geographical races are the chief raw materials from which new species are formed, and it was the different finches on the different Galapagos Islands which first suggested to Darwin that evolution had occurred. Here, to various extents, geographical isolation has assisted the origination of a number of species.

A case in which geographical isolation may be expected to produce its effects at almost any moment now is provided by the gulls (figure 2). These birds occupy a zone shaped like a ring round the North Pole and form what B. Rensch has called a chain of races. Starting with the British lesser black-backed gull, with its dark mantle and yellow legs, this is found to grade into the Scandinavian lesser black-backed gull, and, continuing in an easterly direction round the chain, this in turn grades into the Siberian Vega gull with its lighter mantle and dull flesh-coloured legs. The Siberian gull grades into the American herring gull, which in turn grades into the British herring gull, with its light mantle and pinkish legs. Although the British lesser black-backed gull may be regarded as belonging to the same species as all the other gulls in the chain to the east of it, when it is compared with the other end of the chain represented by the British herring gull the two may almost be regarded as separate species. Already they differ not only in colour but in habits, for the latter nests on cliffs and is dispersive in winter, whereas the former breeds inland on moors and is migratory in winter. If at any time the chain becomes severed by the erection of a sterility barrier at any point, either through inability to breed or through a rupture of the chain by local extinction of the gull population, the two British gulls will effectively have originated new species.

Geographical isolation is important for the origin of species of plants as well as of animals, but there is another form of isolation which appears to be restricted to plants and involves the sudden erection of sterility barriers between individuals in the same population as a result of changes in the chromosome mechanism. This is known as genetic isolation. When *Primula verticillata* is crossed with *Primula floribunda*, hybrid offspring are produced, but they are sterile because the chromosomes of one parent species are incompatible with those of the other, and the intricate machinery involved in the formation of germ-cells is thrown out of gear. Occasionally, however, the hybrid plant undergoes doubling of its chromosomes, a condition known as polyploidy, and when that has occurred the hybrid is able to breed with hybrids similar to itself because all the chromosomes have compatible partners, but it is sterile in respect of both parent species. Furthermore, the hybrid is not only true-breeding but is different in structure and in habit from each of its parent species. It therefore fulfils all the criteria of a species and has been called *Primula kewensis*. Many other new species have originated by intentional hybridization and accidental polyploidy in this way. Some of these artificially produced species have been found to be identical with, and to breed with, wild species, and this is the proof that this method of species-formation occurs in nature.

THE CENTENARY OF EVOLUTION BY NATURAL SELECTION

In conclusion, it may be said that during the hundred years that have elapsed since Darwin and Wallace first published their theory, the fact of organic evolution is now universally accepted and its mechanism has been formally explained.

The alternative to evolution is so naïve that it comes as a shock to realize that as recently as one hundred years ago, ideas such as called for the following questions could still be current: 'Do they really believe that at innumerable periods in the earth's history certain elemental atoms have been commanded suddenly to flash into living tissues? Do they believe that at each supposed act of creation one individual or many were produced? Were all the infinitely numerous kinds of animals and plants created as eggs or seeds, or as full grown? And in the case of mammals, were they created bearing the false marks of nourishment from the mother's womb?' Darwin might well allow himself to ask these questions, for he and Wallace had found the answer to them.

So soundly was the theory of evolution by natural selection grounded that research does

nothing but confirm the links in its chain of evidence and the inferences to be drawn from them. Its field has extended from the explanation of the production of plants and animals to every aspect of the intellectual life of man, and it would be imprudent to doubt that its greatest triumph may yet lie in the highest aspect of that life. Some persons have attempted to discredit natural selection, on the grounds that being a destructive agent it cannot produce anything new or make the fit fitter. Such persons have only demonstrated that they have neither understood the problem nor studied 'The Origin of Species', in which Darwin carefully pointed out that 'several writers have misapprehended or objected to the term Natural Selection. Some have even imagined that natural selection induces variability, whereas it implies only the preservation of such variations as arise and are beneficial to the being under its conditions of life.' Variation produces novelties at random, but selection determines which are preserved. Only a genius could have discovered a key of such simplicity to so great a problem. Only ignorance, neglect of truth, or prejudice could actuate those who, in the present state of knowledge, without discovering new facts in the laboratory or in the field, seek to impugn the scientific evidence for evolution.

With such new formulations as may be required, the concept of evolution by natural selection continues and will continue to provide what Darwin hoped when he wrote in 1837 in his Notebook: 'My theory would give zest to recent and fossil comparative anatomy; it would lead to the study of instincts, heredity and mind . . . to closest examination of hybridity—to what circumstances favour crossing and what prevents it—and generation, causes of change in order to know what we have come from and to what we tend. This and direct examination of direct passages of structure of species, might lead to laws of change, which would then be the main object of study, to guide our speculations.'

With the same confidence as it accepts Copernicus's demonstration of the movement of the Earth round the Sun and Newton's formulation of the laws of this movement, science can now celebrate the centenary of the first general principle to be discovered applicable to the entire realm of living beings.

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A progress report on titanium

N. P. INGLIS and M. K. McQUILLAN

The introduction of a new structural metal is so rare that the story of the research and development involved would in any circumstances be interesting. This is particularly so for titanium, which has changed from a laboratory exhibit to an industrially important metal within the space of about ten years. The technical problems of its extraction, melting, alloying, and processing have been very considerable, but they have been so far solved that world production of titanium has risen from 3 tons in 1948 to 25 000 tons in 1957.

As long ago as 1791 the existence of titanium was recognized by William Gregor, the English chemist and mineralogist, and three years later it was independently discovered by the German chemist Martin Klaproth. Not until 1925, however, was the metal produced in a form pure enough for its properties to be accurately assessed. Realization that titanium both has an exceptional combination of physical properties and is very widely distributed in nature—of the truly structural metals only aluminium, iron, and magnesium are more abundant—made the metal of great interest to engineers, especially those in the aeronautical field.

The present price of granular titanium is about 16s. per pound, and that of wrought forms ranges from about £2 10s. to £10 per pound, according to the amount of working. The relatively costly processes of extraction, melting, and fabrication make it unlikely that the metal will ever become as cheap as, say, aluminium, but while its wrought forms are now 6 to 10 times as expensive as stainless steel, allowing for the difference in weight, the ratio might well fall to 2 or 3 times if use and production were expanded considerably. These prices and ratios refer to wrought forms like plate, sheet, or bar. As the cost of fabricating these wrought forms into the article required is often appreciable, and is little or no greater for titanium than for stainless steel, the ratio of cost of finished article in titanium compared with steel might ultimately be appreciably less than 2 or 3 to 1.

Since the unusual properties of the metal have been the reason for the great technical effort necessary for its production on an industrial scale, it is appropriate to consider these first.

PROPERTIES

Briefly, the important properties of titanium are its relatively low specific gravity, its ability to form alloys of very high strength, and its considerable corrosion resistance. Before any new structural metal can be established, however, a wide range of its properties must be determined. The research done on the physical and mechanical properties of titanium and its alloys is too extensive even to be summarized here, and our account must be restricted to those properties which engineering designers usually regard as being of the first importance.

Chief among these is mechanical strength, which for engineering purposes must be allied with ductility. In titanium, strength and ductility are very sensitive to the presence of impurities, particularly oxygen, small quantities of which can both strengthen and embrittle the metal. In commercial titanium production the highest degree of purity (i.e. the lowest strength and greatest ductility) is the usual target, on the grounds that it is better to start with a material which is readily workable and to harden it as required. Current 'commercially pure' titanium has therefore a tensile strength of not more than 30 tons/sq. in. and very high ductility. The range of strengths which can be covered by titanium-base alloys, however, extends up to 80 tons/sq. in.

Under repeated loading, titanium has the advantage over most other non-ferrous metals of a definite fatigue limit, as exhibited by steels. Moreover, under complete reversals of stress the fatigue limit is 50–60 per cent of the ultimate stress, which is an exceptionally high ratio. In practice, however, the fatigue strength of any metal is likely to be less than that determined by standard laboratory tests because it is considerably reduced by any sudden changes in cross-section such as result from the notches and grooves found in most engineering parts. Consequently many tests have been carried out to determine the effect of standard notches on the fatigue strength of titanium and its alloys (see figures 1 and 2). For all materials notch-sensitivity is rather greater when tested under conditions of

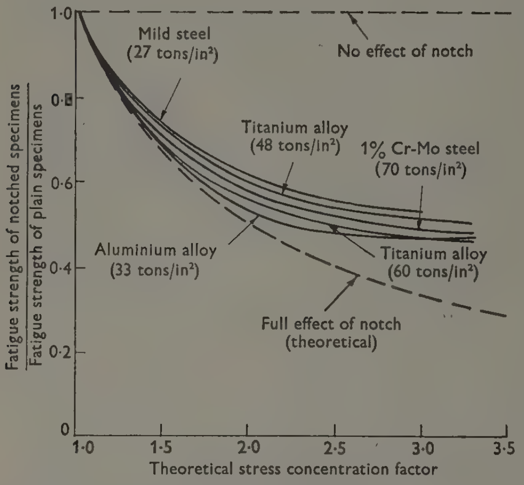

FIGURE 1 – *Notch fatigue sensitivity of various metals when subjected to repetitions of bending stress.*

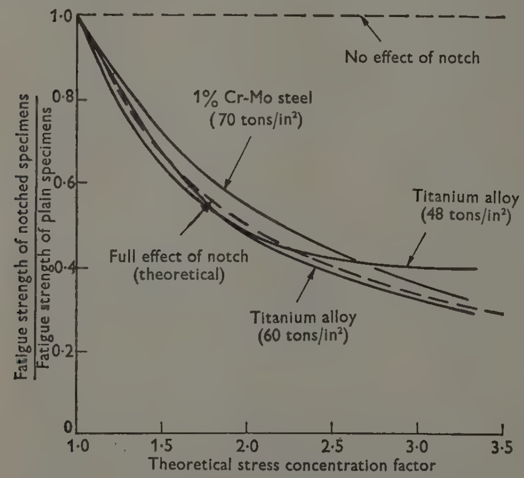

FIGURE 2 – *Notch fatigue sensitivity of various metals when subjected to repetitions of direct stress.*

reversed direct stress than under conditions of reversed bending stress. Under reversed bending stress the notch-sensitivity of titanium and its alloys is much the same as that of other constructional materials. Under reversed direct stress the stronger titanium alloys are rather more notch-sensitive than alloy steels in the same tensile range, but there is no reason to suppose that titanium is unduly sensitive to notch fatigue effects.

At one time it was hoped that titanium would have good load-carrying ability at really high temperatures, but in this respect it has proved disappointing. The strength falls fairly rapidly as the temperature rises, particularly above 400° C (figure 3). Certain alloys have better elevated-temperature strength; but none is outstanding, and the best so far tested had good load-carrying ability up to only 500° C.

Titanium has excellent resistance to corrosion. As with high-chromium steels and aluminium, this is due to the presence of a strong tenacious film of oxide which heals rapidly when damaged. Titanium is in fact resistant to a wider range of corrosive substances than are chromium-nickel austenitic steels. Its superiority to such materials is particularly marked in the case of solutions of chlorides, including sea-water. Even in polluted sea-water, titanium has proved to be unaffected after many thousands of hours under jet-impingement conditions and under conditions which normally give rise to differential aeration effects. Moreover, the corrosion fatigue strength of titanium is actually greater in sea-water than in air; for other corrosion-resistant metals the ratio of the two rarely exceeds 60 per cent.

The outstanding corrosion resistance of titanium has caused growing interest in its use in bone surgery, where its strength, ready availability in wrought form, and complete resistance to body fluids give it many advantages over alternative materials.

Like aluminium, titanium can be anodized in acids, such as sulphuric or phosphoric acids, to produce an even more protective layer of oxide, which may be up to 0·4 μ thick, depending on the applied voltage. The limiting thickness is that at which the electrical resistance of the film prevents further flow of current. Rather surprisingly, electrical contact with the underlying metal can still be made through the anodic film by applying light pressure to the surface—a characteristic which makes titanium useful for constructing commercial anodizing equipment. Anodic polarization can be used to great practical advantage to form self-healing films which allow titanium to be used even in some of the few corrosive media to which it is not normally resistant. This is done by raising the electrical potential of the titanium, either by direct connection to an external potential source, or sometimes more conveniently by coupling the titanium with a piece of more noble metal with which it will form an electrolytic cell when immersed in the corrosive medium. As the anodic film is built up the flow of current virtually ceases, but it is immediately available to repair the film if it should be broken.

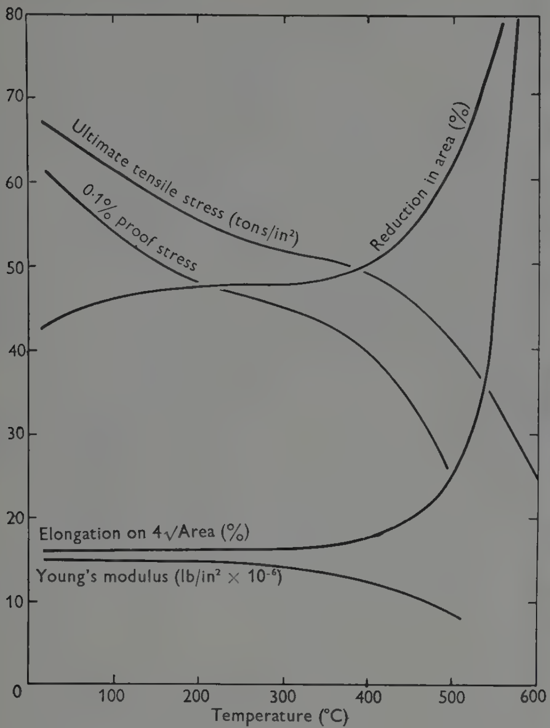

FIGURE 3 – *Effect of temperature on the tensile properties of a typical alpha-beta titanium alloy.*

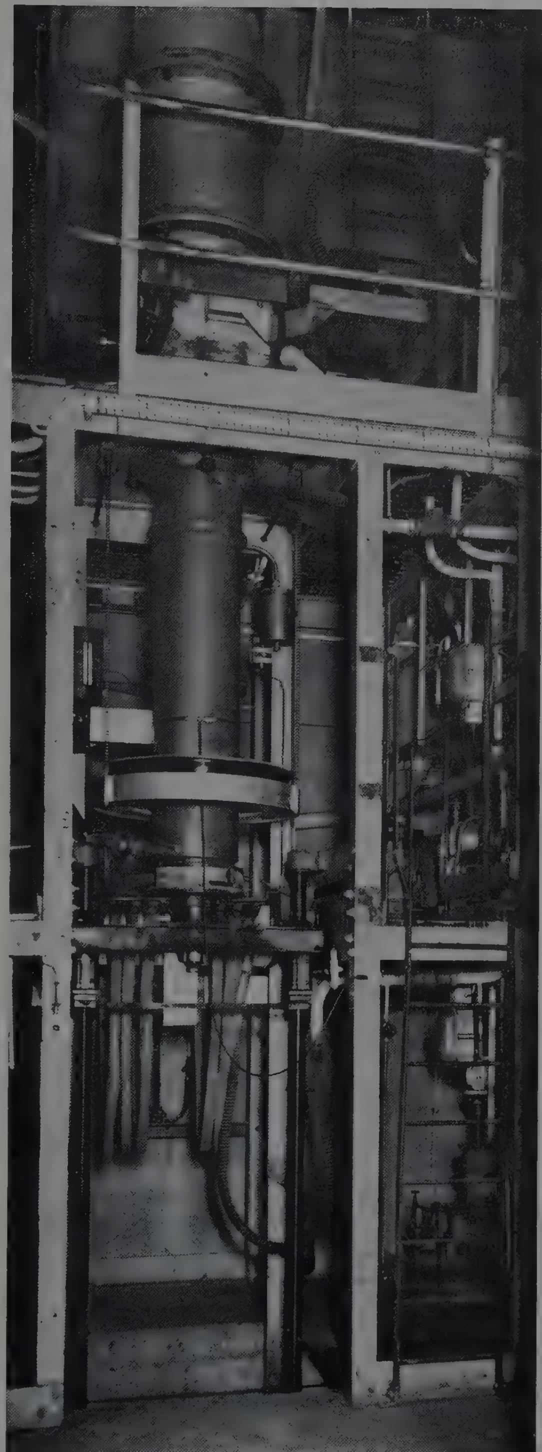

FIGURE 4 – *Production unit for vacuum melting of titanium, housed in blast-proof concrete enclosure.*

TITANIUM ALLOYS

Unalloyed 'commercially pure' titanium has found many uses, especially in sheet form. In the very important aeronautical field, however, the most economically attractive uses for the metal demand high strength combined with low density. To achieve the high strengths necessary, alloys are essential.

The alloying behaviour of titanium is complicated by the fact that titanium is a transition metal, and like all such elements possesses an incompletely filled inner electron shell having an energy level very close to that of the outermost shell. It is usually assumed that in metallic titanium the two shells form a common band of possible electron levels, and that electrons from either can thus take part in bonding processes and electrical conduction. It is not certain, however, that all the electrons in the incompletely filled shell must necessarily contribute to the common band, and much more experimental evidence will be necessary before a truer picture of the electronic structure of titanium can be formulated.

Although existing theories can do little to help in practical alloy development, the behaviour of

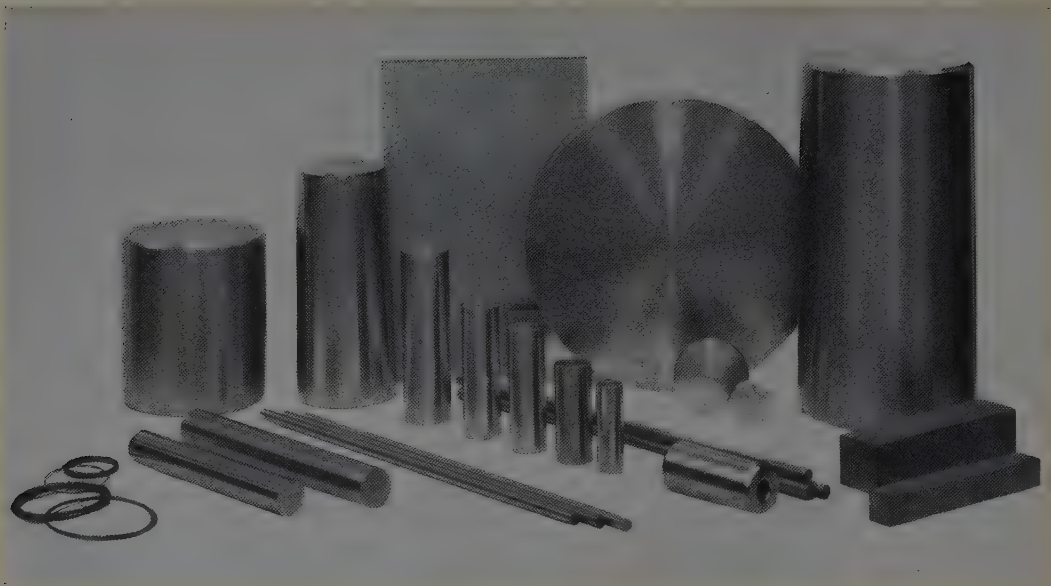

FIGURE 5 – *Examples of wrought forms in titanium and titanium alloys.*

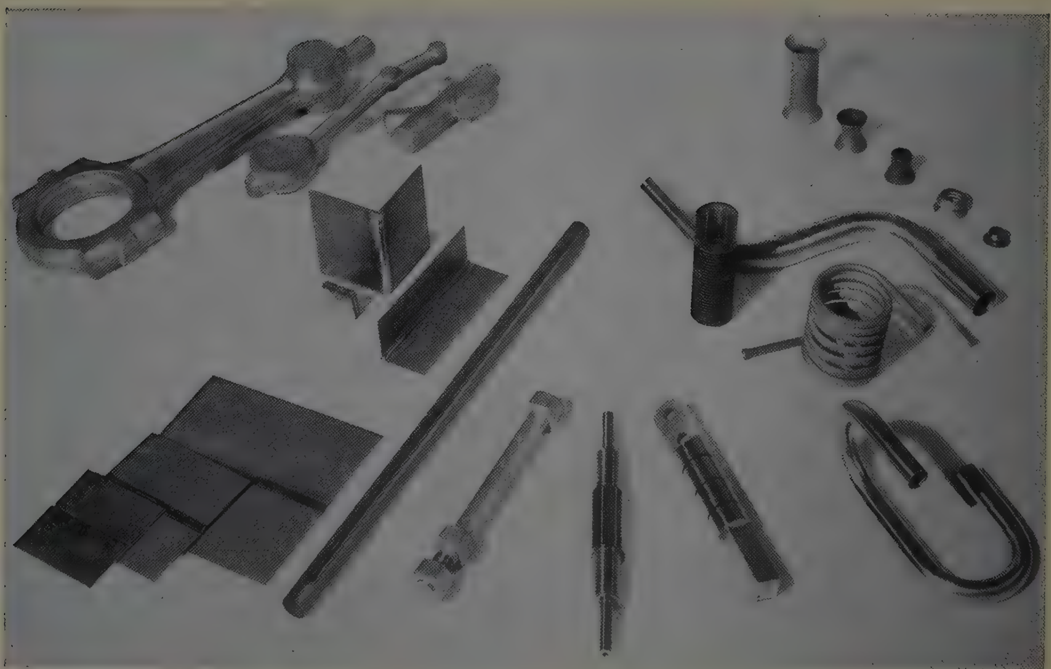

FIGURE 6 – *Examples of forged, welded, machined, and manipulated titanium.*

titanium alloys can be empirically systematized to a useful extent. Broadly speaking, for example, alloys formed between titanium and other transition elements have considerable similarities among themselves and differ in important respects from alloys formed with non-transition elements. This is true in spite of the variation within the two groups of factors—such as atomic size, valency, and electrochemical properties—that are usually important in determining the behaviour of alloys.

Titanium alloys are usually classified in terms of crystal structure. Up to 882·5° C titanium has a hexagonal structure and is designated alpha-titanium; above this it adopts a body-centred cubic form known as beta-titanium. Addition of other elements can stabilize one of these structures at the expense of the other, and by appropriate alloying and heat treatment it is possible to obtain materials that consist entirely of the alpha phase, entirely of the beta phase, or of a mixture of the two. These constitute the principal types of alloy.

Alpha, beta, and alpha-beta alloys each have characteristic mechanical properties. To a large extent this is directly attributable to the different atom-packing arrangements in the two phases, but there may also be an effect due to differences in the electronic interaction between titanium atoms and those of alpha-stabilizing and beta-stabilizing elements.

Alpha alloys are strong, but are difficult to fabricate, especially into sheet. Beta alloys, by contrast, are easy to work but are normally appreciably less strong, and may be unstable if used at elevated temperatures. They have the advantage over alpha alloys that their strength can be made high by heat treatment; even then, however, they tend to have a lower resistance to creep (i.e. to slow deformation under prolonged load at elevated temperatures) than alpha alloys that are of similar strength at ordinary temperatures.

The alpha-beta alloys are intermediate in type. When heat treated, they can combine high strength with rather better ductility than can usually be obtained in other alloys of comparable strength. Most of them contain an element, usually aluminium, which dissolves in and strengthens the alpha phase, together with one or more of the elements that stabilize the beta phase. The latter are usually chosen from among the early transition metals such as manganese, vanadium, niobium, tantalum, and molybdenum. For some time an alloy containing 4 per cent aluminium and 4 per cent manganese has been the most widely used alloy of this class, but there is now a tendency to use new compositions such as 6 per cent aluminium with 4 per cent vanadium and 6–7 per cent aluminium with 3 per cent molybdenum.

The range of elements that can be added to alpha alloys is limited by the very low solubility of many metals in alpha-titanium. So far only aluminium and tin have been used commercially as major additives. Zirconium is another possible major additive, and there are a number of possible minor additives which may give improved properties if their tendency to make the metal brittle and other difficulties can be avoided.

No beta alloys have yet been exploited commercially, principally because they tend to become brittle at elevated temperatures unless a very large proportion of a beta-stabilizing element is added. Nevertheless, beta-type alloys that can be heat treated may eventually be used. Stable beta alloys are also potentially useful in applications demanding high corrosion resistance. A titanium alloy containing 30 per cent of molybdenum, for example, is very promising for use in the construction of chemical plant.

At the present time much attention is being devoted to the development of an alloy for use in sheet form. This must be soft enough for easy fabrication but capable of being considerably strengthened by heat treatment. Several such alloys have been proposed, all containing fairly large amounts of beta-stabilizing elements. In the soft condition they usually contain both alpha and beta phases, the beta being subsequently hardened by heat treatment at a low temperature. Such alloys are now becoming commercially available.

Alpha, beta, and alpha-beta alloys have now been fairly thoroughly explored. Most of the advantages resulting from the purer raw materials made possible by modern methods of extraction have already been realized. Future developments may be expected to include the appearance of new classes of alloys, such as one consisting of a hard intermetallic compound finely dispersed in an alpha matrix. An alloy of this type might be produced by a classical age-hardening process or by tempering the martensitic alpha phase which in a wide range of alloys is formed from the beta phase by a shear process on quenching.

Major improvements, however, will depend on a more fundamental understanding of the metallurgical conditions which limit the extent to which some alloys can be worked and which make others become brittle in use. It can fairly be said that progress is being made in this direction.

EXTRACTION

The need to eliminate as much oxygen as possible determines the type of process by which titanium is extracted from its ores. As it is impossible to reduce the oxygen content to an acceptably low level by direct reduction of the oxide, commercial production is in two stages.

The ore at present used is rutile (TiO_2), although it must eventually be the more plentiful ilmenite ($FeO.TiO_2$). This is first converted to titanium tetrachloride, which after careful purification is reduced by either magnesium or sodium. Magnesium reduction, first applied by W. J. Kroll, has been widely adopted in the United States and Japan. British production, however, depends mainly on sodium reduction, and the most recently constructed plant in the United States also uses this method. The two processes yield metal of much the same purity and at much the same price. Of the two, the sodium reduction method probably has the greater potential for improvement, both economically and in the purity of the product,

As has been stressed, the strength of titanium is very sensitive to the presence of traces of oxygen. Since the strength of a metal is, in general, proportional to its hardness, the hardness of a small melted ingot is generally accepted as a convenient index of purity of the raw metal. Changes in the average hardness of commercial titanium indicate the improvements that have been made in recent years. Very pure titanium, made by thermal decomposition of the tetraiodide, rarely has a hardness lower than 80 D.P.N.[1] The average hardness of titanium now produced in Britain by the sodium reduction process—believed capable of ultimately yielding a still purer product—is 130 D.P.N. Only a few years ago the hardness of commercial titanium was in the range of 160–200 D.P.N.

Much attention has been, and is being, given to electrolytic processes for the extraction of titanium. A short time ago many people were confident that the history of aluminium would be repeated and that chemical reduction would be replaced by electrolysis. Lately, however, confidence in the commercial future of electrolytic methods has waned considerably. This is not due to fundamental difficulties in producing titanium by electrolysis but because such processes seem likely to be more costly than those now used.

Recent work on electrolytic purification of scrap or impure titanium suggests the possibility of a two-stage process whereby very crude metal is first produced and this is then refined electrolytically, but preliminary estimates of cost are not favourable, particularly in the light of proposed economies in existing processes.

MELTING

The extreme reactivity of molten titanium, which no refractory resists, necessitates methods of melting radically different from those used for most other metals. It is now fairly general commercial practice to use direct-current arc melting in a water-cooled copper crucible and to protect the molten material from atmospheric contamination by working in argon or *in vacuo* (figures 4 and 7).

Formerly a water-cooled tungsten or carbon electrode was employed, the titanium being fed into the crucible in the form of granules or pellets. In this method difficulties were encountered, however, through impurities being picked up and the ingot not being homogeneous. Although a furnace with a non-consumable carbon electrode was developed to a type which reduced carbon contamination to less than 0·05 per cent, it became abundantly clear that a consumable titanium electrode would have the following overriding advantages:

1. Elimination of carbon (or tungsten) contamination. Even at the 0·05 per cent level this could be detrimental in certain alloys, especially if segregation occurred.
2. Consumable-electrode furnaces are more readily adapted for operation *in vacuo*.
3. Higher melting rate for a given power input.
4. Avoidance of the not inconsiderable engineering difficulties of maintaining a uniform separate feed of titanium and alloying elements.

Consumable electrodes for feeding into the furnaces are made by mixing raw titanium granules with the desired alloying elements and compressing the mixture into pieces strong enough to be handled, pressures of 10–20 tons/in^2 being required. These pieces are welded together until they correspond to the weight of the ingot to be produced, which may be up to 2000 lb in Britain and frequently appreciably more in the United States. It may be remarked that the granular raw

[1] Some confusion can result from the use of more than one scale of hardness. In Britain it is usual to use the diamond pyramid number (D.P.N.) rather than the standard Brinell hardness number. Within the range with which we are here concerned the standard Brinell hardness number is about ten units less than the D.P.N. The sub-standard Brinell test favoured by United States suppliers gives a hardness number ten units lower still, i.e. some twenty units less than D.P.N.

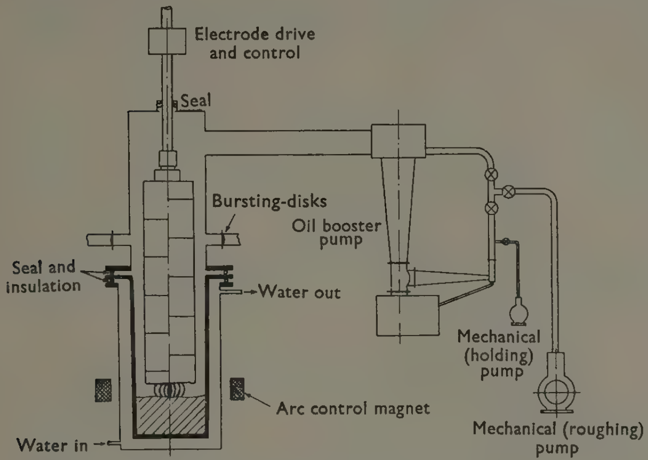

FIGURE 7 – *Diagrammatic representation of vacuum melting furnace with consumable electrode.*

titanium produced by sodium reduction is very much more easily compacted than the coarser product of the Kroll process.

The argon atmosphere used in furnaces operating with non-consumable electrodes is now usually replaced by a vacuum when consumable electrodes are used, and even the largest furnaces are being operated at pressures as low as 5–20 μ of mercury. The operating pressure has to be modified, however, when the alloy to be melted contains relatively volatile elements such as manganese. Double melting, in which the ingot made in the first melting becomes the consumable electrode in the second, has become fairly general. This improves homogeneity, gives a better surface to the ingot, and reduces the hydrogen content.

Arc melting in water-cooled crucibles has the disadvantage of being potentially dangerous. If the wall of the crucible should become perforated, water will come into contact with titanium at about 1700° C. The resulting generation of steam may cause an explosion, and this may be followed by a hydrogen-air explosion if the crucible should burst. Great precautions are taken to avoid such events, and to prevent their being dangerous if they do occur. Bursting-disks are fitted (figure 7) to prevent the build-up of steam pressure. Furnaces are situated behind thick concrete walls and operated by remote control (figure 4).

The intensive development work done on melting methods for titanium is likely to prove extremely valuable for some other of the newer metals, such as zirconium, in which there is a growing interest. Melting in a vacuum is also of interest for some of the older metals, the properties of which are often appreciably modified by the vacuum-melting process.

FABRICATION

As might be expected, the conversion of titanium ingots to plate, bar, and other wrought forms has generally been carried out with equipment used for similar processes on other metals. Despite the relatively high melting point of titanium, no mechanical difficulties have been encountered in forging or hot rolling. Cold rolling of 'commercially pure' titanium is also straightforward and calls for no comment, though this is not true for alloys.

Hot working

The difficulties experienced here are chemical rather than mechanical. They are concerned with the prevention of undue contamination by oxygen, nitrogen, or hydrogen, with which titanium reacts readily at the temperatures involved. Fortunately, diffusion of oxygen and nitrogen in titanium is relatively slow, and by careful heating procedures these impurities can be confined to a thin surface layer which can be removed by mechanical or chemical methods. Hydrogen, on the other hand, diffuses very readily, and although it can be removed by heating *in vacuo*, the more usual course is to prevent trouble arising by strict control of the furnace atmosphere.

Hot extrusion has not proved as successful for titanium as for many other metals. This is because when forced through a die titanium is prone to seize, causing imperfections in the metal surface. Much attention is being given to this problem, the solution of which clearly depends upon effective high-temperature lubrication. Some success has been achieved by sheathing the workpiece in copper and by the use of glass as a lubricant, but the latter has so far proved less satisfactory for titanium than for other metals.

Cold working

The cold rolling of alloys of high tensile strength is possible only by repeated small reductions, with frequent intermediate annealing. The difficulty is not specific to titanium: it is encountered in the cold rolling of any metal with a tensile strength of 60–70 tons/in^2 and a high ratio of yield stress to ultimate stress. In the case of titanium, however, the difficulty is so great that, with equipment now available in the metal industry, thin sheet (of the

order of 0·05 cm thickness) in the harder alloys has so far been almost entirely produced by hot rolling. It is usual to pack a number of thin sheets together and roll them within steel cover-plates. Such a method gives, however, poorer surface finish and dimensional tolerance than if finishing were done by cold rolling, and ways of overcoming the difficulty are being studied.

The problem can be approached in two main ways, both of which are being closely investigated. The metallurgist's approach is to find an alloy that is soft enough to be rolled easily when cold and can then be strengthened by heat treatment. The engineer can seek a solution by studying the effect of surface treatment and lubrication on the rolling loads required: for example, it has been shown in some very recent experiments that a newly developed oil can reduce by 50 per cent the load normally required to achieve a given reduction in thickness.

As in extrusion, cold drawing is hampered by titanium's tendency to seize, but various methods of reducing this difficulty are available. In fine wire drawing, for example, silver-plating of the stock has proved a very satisfactory method of lubrication and one which remains effective even when drawing is continued after annealing. Various chemical treatments—such as treating with cyanide or phosphate or controlled oxidation at a high temperature—are also useful in providing a surface which will hold a lubricant and prevent direct contact between the metal and the die.

Welding

Titanium may be welded by most of the normal methods provided that certain specific precautions are observed, such as prevention of contamination by oxygen, nitrogen, and hydrogen.

In fusion welding, only arc processes carried out in an inert atmosphere can provide sufficient protection for the heated metal. Tungsten arc welding, shielded by inert gas, is usually adopted, but special baffles have been designed to improve the gas shielding, together with a water-cooling system to chill the heated metal as quickly as possible. In appropriate circumstances fusion welding can be done in a chamber filled with inert gas, which obviates the need for either baffles or cooling. Pressure welding is possible at temperatures of about 800° C provided the surfaces to be joined have been very carefully cleaned and abraded.

The welding of ordinary commercial titanium and of alpha alloys need have no harmful effect on the mechanical properties of the metal, but this is not true of alpha-beta alloys. Welded joints in such alloys are brittle, even where contamination is negligible, owing to reactions which occur in them on cooling. Heat treatment can improve the ductility of samples made brittle in welding, but does not usually fully restore the original properties.

CONCLUSION

Although the technological development of titanium has been considerable over the past ten years, much remains to be done before the metal can be exploited to its fullest advantage. In particular, the main objective of future research must be a reduction in costs. Many factors could contribute to such a reduction, but the principal ones are likely to be:

1. Increased production, resulting from more extensive use.
2. Improved methods of fabrication, resulting in the final article containing a much higher percentage than at present of the original titanium used.
3. Specific utilization of the unique combination of properties of the metal instead of, as at present, using it merely as a substitute for other metals.

These factors, it is suggested, are at present more important than improvements in the method of reduction and improvements in alloys, although progress in both fields would be of great value.

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Rockets and satellites in scientific research

H. S. W. MASSEY

Any day may bring the unheralded announcement of an important new achievement in the field of rockets and satellites. To review progress is difficult, but because of its many far-reaching implications it is important to see the field as a whole. Professor Massey considers here both what has been achieved and the likely course of future developments. He stresses that satellites and vertical sounding rockets are not competitive but complementary.

Scientific study of the Earth's atmosphere and of the surrounding interplanetary space has been proceeding for a long time, but until 1945 it was possible to take instruments only up to altitudes of eighteen miles or so, in exploratory balloons, in order to make direct measurements of atmospheric properties. There is much of interest and importance in the atmosphere at much higher altitudes—the ionosphere really begins only about 60 miles up and extends up to several hundred miles; auroral displays occur mainly at heights above 60 miles; the atmospheric currents responsible for the quiet-day magnetic variations are strongest between 60 and 90 miles; meteors rarely penetrate closer than 60 miles from the surface before being evaporated; and so on. We now possess a considerable store of knowledge of these upper atmospheric phenomena; but much more remains to be done, and the sounding rocket is becoming of increasing importance in this direction. A rocket carries with it not only its fuel, but also its own oxidant, so that as far as its propulsion is concerned, it is independent of its surroundings.

In view of the fact that even today most of our knowledge of upper atmospheric phenomena has been derived from observations using ground-based radio or sonic probing, spectroscopic studies, magnetic measurements, and so on, it may well be asked why it is necessary to use sounding rockets at all. The answer is that although they involve difficult and expensive techniques, for some purposes their use is essential.

The most important of these is the study of the solar radiation before it enters the absorbing atmosphere. It is the interaction of the solar electromagnetic radiation with the atmosphere that produces the ionosphere and the night airglow, and affects the chemical constitution of the atmosphere (above 60 miles the oxygen is largely atomic). Only radiation that has not interacted reaches the ground, and therefore its observation provides no useful information about the primary origin of the solar-dependent phenomena. To observe the radiation that is effective in the atmosphere, it is necessary to send measuring equipment up to altitudes above the regions in which the interaction is strong. The sounding rocket is the only vehicle that can carry equipment to the altitudes involved.

Apart from this most important function, there are many others that cannot be fulfilled by indirect ground-based studies. These include measurement of the variation of electron concentration in the ionosphere between the main layers and above the uppermost (F_2 layer) maximum; the nature of the ions at different heights in the ionosphere; the variation with height of the intensities of the different lines in the night airglow; the relative concentration of atomic and molecular oxygen at high altitudes; and others.

Another possibility which is opened up is that of experimenting with the upper atmosphere. At any desired altitude the local concentration of a particular constituent may be greatly increased by ejection of this material from a rocket. The resulting effects may be observed with ground-based instruments. Experiments of this kind have been carried out with very interesting results, using sodium and also nitric oxide as the ejected material (see page 88).

Apart from these unique facilities, it is also an advantage to be able to make measurements directly instead of deriving them indirectly. It is usually possible to obtain more detailed knowledge of the variation with height of a particular quantity. It must always be remembered, however, that the difficulty of making the measurements from a rocket is often so considerable that undue emphasis should not be placed on data obtained in this way until the techniques involved have been thoroughly tested and, as far as possible, checked with other methods.

THE NEED FOR ARTIFICIAL SATELLITES

Many important upper atmospheric phenomena not only vary markedly with latitude and longitude, but are variable in time, and the great limitation of the sounding rocket is the short time of flight—a few minutes at most. The sun is a variable star, and the changes which occur in its radiation produce correlated effects in the atmosphere. During disturbed periods the solar electromagnetic radiation may change appreciably, but in addition streams of charged particles may be emitted. These produce effects on the Earth that depend very much on the latitude, because the Earth's magnetic field directs the charged particles to the auroral zones. The latter are belts usually about 5° wide, located about 23° from either pole. Among these effects are magnetic and ionospheric storms (including polar black-outs) and auroral displays. Radio fade-outs are also due to solar activity, but they result from increased emission of ultra-violet or X-radiation during solar flares.

It is clear that for the study of these important aspects of atmospheric phenomena, sounding rockets which travel rapidly over a nearly vertical trajectory are very inadequate. For this reason it is appropriate to consider what can be achieved with artificial satellites. These also require the use of high-altitude rockets, but in this case to take an instrument container up to a suitable altitude and to launch it there in the right direction and with the speed necessary for it to circulate as a satellite. If the lifetime of such a satellite is long enough and the data obtained by its measuring instruments can be transmitted to the ground in the form of coded radio signals, chosen atmospheric properties, or the solar radiation itself, can be studied continuously not only as a function of time, but also over the whole, or a large part, of the Earth's surface. The problems involved in doing this will be described briefly later in this review. It is quite clear from the progress already made that such satellites will be a permanent feature of future atmospheric, solar, cosmic ray, and space research.

It is of interest to point out here that precision observation of the orbit of a satellite circulating outside the effective atmosphere will make possible the more exact determination of the figure and density distribution of the Earth. On the other hand, if the orbit passes through the high atmosphere it is possible, from observations of the orbit, to obtain information about the density of this part of the atmosphere.

The introduction of artificial satellites does not mean the supersession of the vertical sounding rocket. If it is to have a useful life, a satellite must circulate at altitudes above 120 miles, so that variations of properties in the vertical direction below this altitude must still be measured by rocket sounding. The two techniques are complementary rather than competitive.

SOUNDING ROCKETS

The first rockets to be used for atmospheric research were captured German V-2 military rockets. These had a gross launching weight of about 12 tons, and had a total length of 46 feet and a maximum diameter of 65 in. They employed liquid propellents making up over two-thirds of the weight at launching; the fuel was alcohol and the oxidant liquid oxygen. An instrument load of 2200 pounds could be carried in these rockets up to a height of 100 miles. The first upper atmospheric observations made with rocket-borne instruments were carried out in the United States in 1946 using V-2 rockets. Over 60 instrumental flights have been made with them.

Early in 1949 a large rocket, the Viking, designed and developed in the United States, was used for atmospheric sounding. It will transport an instrument load of 750 pounds to a height of over 130 miles and attain a maximum velocity of about 5400 feet per second. Like the V-2, it is stabilized, while the motor is burning, against roll, pitch, and yaw by a control system; in addition, the later versions are fitted with controls that are effective after burn-out. The Viking is too expensive for normal vertical-sounding purposes, but is important in the American Vanguard programme (page 89); the first stage of the launching rocket is essentially a Viking rocket.

The Aerobee rocket was the first designed in the United States purely for upper atmospheric sounding. It is about 20 feet long, has a gross weight at launching of 1068 pounds, and is capable of carrying a payload of 150 pounds to an altitude of 60 miles. Recently an improved version, known as the Aerobee-Hi, has been developed, and this will carry equipment to a little less than twice the height. A research rocket with liquid propellent similar to the Aerobee, has been developed in France for atmospheric sounding. It is known as Véronique.

Another example of a sounding rocket using a liquid propellent is the Russian meteorological rocket. This uses nitric acid as oxidant and alcohol as fuel; it attains an altitude of about 60 miles. No information is available at the time of writing

about the Russian geophysical rocket, which can attain much greater altitudes.

The first single-stage sounding rocket using solid fuel is the Skylark, designed in Britain at the Royal Aircraft Establishment. This is being employed in the British Upper Atmospheric Research Programme. It is capable of carrying a payload of 150 pounds to altitudes of 120 miles. At launching it weighs over 1 ton.

Much smaller rockets may be employed if multi-stage or other combined systems are used. Thus a balloon may be used to carry a rocket up to an altitude of 80 000 feet, well above the dense atmosphere, the resistance of which very substantially increases the propellent required for a ground-launched rocket. By firing from 80 000 feet the same minimum altitude may be achieved with a much smaller rocket. This 'rockoon' combination has been used very effectively by American scientists. As an elaborate launcher is not required, firings may be carried out in different locations, the only extra complication being the safety requirements—it is not easy to predict where a balloon-launched rocket will eventually come back to earth. Very recently a very high altitude, between 1000 and 4000 miles, was attained in American experimental firings at Eniwetok by exploiting the rockoon technique to the full, with a large balloon and a large rocket.

The Australian and Japanese high-altitude rocket projects both use the rockoon principle.

Two-stage rockets that are in use in the American programme are the so-called Nike-Deacon and Nike-Cajun combinations. In these, the Nike rocket motor is used to take the small Deacon or Cajun rockets quickly up to altitudes comparable with that reached by the balloon in a rockoon.

Development of sounding rockets that are still more economical is proceeding steadily, particularly in the United States and Japan. Thus in the United States, van Allen has used a rocket only 3 inches in diameter which when launched from a balloon, reaches a height of 65 miles.

TECHNIQUE OF MEASUREMENT WITH ROCKET-BORNE INSTRUMENTS

It is not possible within the space of this article to describe the various techniques employed in making measurements with instruments carried aloft in rockets. The chief difficulties are the limitations of space and weight; the shocks and vibration to which the instruments are subjected; the tendency of uncontrolled rockets to pitch, yaw, and roll; the short flight-time; the problem of recovering information; and the modification of the local atmosphere produced by the rocket itself.

The last of these is often a serious complication For example, it is impossible to measure ambient pressures less than 10^{-5} mm Hg with rocket-borne pressure gauges, because the pressure of gas given off from the rocket itself exceeds this. The Russian meteorological rocket avoids this kind of difficulty by ejecting the measuring instrument in a container from the rocket at a suitable altitude. This container is equipped with a parachute; it at first rises for some time and then falls comparatively slowly. Measurements are made only after ejection from the rocket.

Although several techniques for recovery of the instrument chamber from a rocket have been devised and operated, it is usual to arrange for the measurements to be converted to electrical impulses in a radio transmitter in the rocket and transmitted to ground as coded signals during flight.

ACHIEVEMENTS AND PROSPECTS OF RESEARCH WITH SOUNDING ROCKETS

Up to the time of writing almost all the published results of research using high-altitude rockets have been those obtained under the aegis of the United States Rocket Panel. This work dates back to 1946. It is not certain when the Russian research programme was initiated. Results of atmospheric structure measurements using the Russian meteorological rocket (see above and page 88) have been published during the past year, and it is likely that more results of Russian investigations will be published in the fairly near future. The British programme, which involves the firing at the Woomera rocket range in Australia, of Skylark rockets fitted with suitable instruments, is just coming into full operation. The French, Australian, and Japanese programmes are also likely to come into full operation during the International Geophysical Year.

Most of the American launchings have taken place at White Sands, New Mexico, but there have been firings from ships at sea. As a special contribution to the I.G.Y., a firing range has been established with Canadian co-operation at Fort Churchill in Canada, which is in the specially interesting auroral zone. An extensive series of rockoon firings over a latitude range from California to the Antarctic is also being carried out. The Russian I.G.Y. programme includes 100 firings of meteorological rockets in Franz-Josef Land and the Antarctic, as well as many launchings of higher-altitude rockets.

As far as results are concerned, we must perforce confine ourselves almost exclusively to the American work, which is however both extensive and fruitful. The investigations carried out concern the solar radiation; the pressure, density, temperature, and wind distribution; the electron concentration and the composition of the ionosphere; the intensity distribution of radiation in the night airglow; the cosmic radiation; the flux of meteors and meteorites; the ozone and atomic oxygen content; the radiation present in the atmosphere above the auroral zone; and other features.

In the short space available here it is possible to single out only one or two specially interesting results. The nature of the incident solar radiation, although understandable in a general sense, has turned out to be rather different from that assumed earlier. In the visible region the sunlight is of an intensity and colour distribution not very different from that radiated by a black body at 6000° K. At shorter wavelengths the intensity falls well below this; it is, for example, only about one-fortieth for ultra-violet light at 2000 Å. On the other hand, in the X-ray region at wavelengths of 1–50 Å, the intensity is very much greater than would be expected for a black body at 6000° K. These X-rays probably come from the solar corona, the outer atmosphere of the sun, which is known to have a kinetic temperature of 1 000 000° K. Much interesting work is still to be done in the wavelength range between 50 and 1200 Å and also on the variability of the radiation at all wavelengths.

The observations of pressure and temperature made up to 50 miles using the Russian meteorological rocket agree quite well with those obtained by the Americans. There still seem, however, to be discrepancies at higher altitudes, indicating that the accuracy obtained at these altitudes still leaves much to be desired. For checking purposes alone the advantage of having many more rocket programmes in operation is clear.

One other remarkable feature of the American work has been the successful introduction of upper atmospheric experiments. In 1954, 5 pounds of sodium vapour was ejected at twilight from an Aerobee rocket at an altitude of 40 miles. It gave rise to a brilliant yellow fluorescence, due to irradiation by sunlight. This was visible with the naked eye for over twenty minutes, even at points 300 miles away from the launching site. There is normally only about 1 ton of sodium in the high atmosphere, but it contributes to the night airglow and exhibits a fluorescence at twilight that was intensified locally in this remarkable experiment.

In other experiments nitric oxide gas was ejected from rockets. During the day the nitric oxide cloud, ejected below 60 miles, is ionized by the sunlight and may be traced by radar reflection —there are possibilities here of artificially improving conditions for signalling. At night the gas was ejected at a higher altitude, where the oxygen is mainly atomic. Due to the reactions

$$NO + O \rightarrow NO_2 \quad \text{and} \quad NO_2 + O \rightarrow NO + O_2$$

which involve the catalytic recombination of oxygen, a great deal of radiation was emitted. Consequently the ejection produced a glowing cloud providing visual demonstration of the atomic character of some of the oxygen at the level concerned.

Scientific observation by ground equipment may be made on these artificially produced glows in the sky, and this can lead to very valuable information about the atmosphere. It may even provide new photochemical data from an environment in which complications due to surface effects are absent.

THE FIRST SATELLITES

In order that a body of mass m should circulate as a satellite round the Earth in a circular orbit of radius R measured from the centre of the Earth, it must move at a speed V given by

$$\frac{mV^2}{R} = \frac{GmM}{R^2}$$

where M is the mass of the Earth and G the constant of gravitation in the orbit. This equation merely expresses the condition that the pull of the Earth's gravity must be balanced by the centrifugal force. If r is the radius of the Earth,

$$\frac{GM}{r^2} = g,$$

the acceleration due to gravity at the surface of the Earth. Hence

$$V = \sqrt{(gr^2/R)}$$

If the orbit is not too far away from the Earth so that $r \simeq R$, we find that

$$V = 18\,000 \text{ miles per hour.}$$

In order to give the satellite a sufficiently long life to be useful, the initial orbit, which will in fact be elliptical rather than circular, should not approach too close to the surface. Otherwise the satellite will enter dense atmosphere at high speed and be disintegrated or evaporated by the resultant heating. This minimum distance of approach can be placed at about 100 miles or so.

The practical problem is one of transporting a satellite, of sufficient size and weight to be useful for tracking and as an instrument container, to a height greater than 100 miles and then propelling it in a direction close to horizontal with a speed of 18 000 miles per hour or greater. This is a difficult control problem. The more reserve speed available the less accurate need be the direction of launching.

In the American Vanguard programme the satellite as planned weighs 20 pounds and is about 20 inches in diameter. The launching operation employs a three-stage rocket with a total weight of 11 tons. The first and heaviest stage is essentially a Viking motor, and the control mechanism is housed in the second stage. The first Russian satellite weighed 184 pounds. The second, in which the third-stage rocket and the satellite were not separated, was no less than six times heavier. There is at the time of writing no information available about the launching techniques employed, but it seems certain that much larger first-stage rocket motors were used than in the first satellite.

The first two Russian satellites both included radio beacons transmitting signals at 20 and at 40 Mc/s for periods of three weeks and one week respectively. These limited lives were probably due to battery failure, as the acceptable battery weight was restricted. In future satellites, power will be supplied from solar batteries, which will have very long life.

The first Russian satellite contained no equipment apart from the radio transmitters, but much interesting information has been obtained from its observation as well as that of the third-stage rocket case which accompanied it. In Britain, many universities and government departments recorded the radio signals. They have observed the Doppler frequency shifts due to the speed of the satellite in the line of sight and have used radio interferometers for direction finding. Visual, and particularly radar, methods of tracking have also been used with success. The frequencies chosen by the Russians are markedly affected by the ionosphere, so that the observed fading and refraction of the radio signals will provide much new information of importance about the upper ionosphere. The analysis of data obtained is still in progress.

The effect of air resistance on the first Russian satellite and rocket case was very marked, and both objects have now spiralled into the dense atmosphere and disintegrated. The minimum distance of approach in initial orbit was about 120 miles and its maximum about 580 miles. Early estimates of air density based on the number of revolutions performed before disintegration are consistent with estimates made by atmospheric physicists.

The second Russian satellite contained, in addition to the radio beacon, equipment for studying cosmic and solar radiation; a pressurized cabin with a dog; and additional radio for the transmission of observed data back to the ground. The dog's cabin included a store of food, a system of air conditioning, and apparatus for recording pulse and breathing rate, blood pressure, and electrocardiograms. No details are yet available about the results of the measurements, but it appears that a considerable amount of data was obtained.

The first American satellite, Explorer, launched by the Jupiter C research rocket, was cylindrical, with a length of 80 inches and diameter 6 inches, and weighed 30·8 pounds. The instrumentation included cosmic ray equipment, gauges for measuring internal and skin temperatures, and a microphone and erosion gauges for measuring the impact of micrometeorites. The radio beacons operated at 108 Mc/s, since radiation at this frequency suffers substantially no refraction in passage through the ionosphere and hence may be used to give accurate orbit data. Plans have also been announced for a satellite containing a transmitting television camera.

We can expect, in future satellites, more and more elaborate experimental equipment. The American I.G.Y. programme also includes magnetic field, and solar and earth radiation studies. Much can be done even by those countries who are not launching satellites, for observation of the paths of the objects can of itself yield results of importance. We can look forward to great activity in this field, reaching further and further out into space without the necessity of manned flight.

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Succulent plants

W. O. JAMES

Succulent plants are found in many very different geographical areas and in many families. Succulence, a development whose purpose is apparently to ensure the plant's survival in areas of uncertain water supply, can occur in any part of the plant and to widely varying extents, although the mechanism by which it is produced is not known. The occurrence and methods of experimental study of succulence are described here.

Succulence consists in the extensive developments of a simple parenchyma in which the cells are thin membranes surrounding drops of water having diameters of the order 10^{-4} cm. The cells tend to be spherical, but may be elongated in some particular direction (figure 14). The degree of succulence is expressed as the ratio of weight to surface. The unit commonly used is the number of grams of contained water per square centimetre of surface. For a given cell weight this ratio has a limiting value. Some cacti and *Conophyta* approach this limit closely (figures 1, 4, and 5). Compared with the diffuse structure more normal among plants this represents a great reduction of surface, and an *Echinocactus* weighing 3 kg was found to have only 1/300th of the surface area of an *Aristolochia sipho* of equal weight.

Succulence may develop in any part of a plant. The more or less spherical cacti have non-succulent roots underground and have reduced their leaves to thorns or eliminated them altogether. They are the most advanced examples of succulence in the stem. Extremes of leaf succulence are achieved by the 'flowering stones', *Conophytum*, *Lithops* (figure 6), and other genera of the Aizoaceae, whose spheroidal bodies consist of two closely appressed leaves and little else. The leaves may even be entirely fused except for a small pore through which the flower emerges (figure 1). Less common is succulence of the flower, which nevertheless is highly developed in those of *Stapelia* species, which have the appearance, more or less the texture, and sometimes the smell, of over-ripe meat. The successful pollination of these flowers depends upon their attractiveness to blowflies (figure 2). All intermediate degrees of succulence leading up to these extreme types exists in different species. An advancing series of leaf succulence is shown in figures 7–10.

Succulence is virtually unknown outside the angiosperms, but within this group it occurs in all members of several large families, notably the Aizoaceae, Crassulaceae, and Cactaceae. It also occurs in many of the Liliaceae and Euphorbiaceae, and more rarely in taxonomically isolated genera such as the composite *Kleinias* (figure 10).

The popular association of succulents with deserts represents only part of the truth. Even the cacti themselves are found in every latitude from British Columbia to Tierra del Fuego. Some *Opuntias* are weeds in North American prairie pastures, where they nestle among the herbage to the discomfort of grazing animals. One species has naturalized itself in the European Alps, and other cacti are found in the high Andes in the snow. The *Sempervivums* (e.g. figure 13) produce their rosettes of succulent leaves in mountain ranges from the Caucasus to the Pyrenees; the *Bryophyllums*, members of the same family, come from the West Indian tropics. Another group of cacti, *Rhipsalis* and the *Epiphyllums* (acclimatized in Victorian parlours), are epiphytes from the Central and South American rain forests. The chenopod succulents (*Salicornia*, etc.) provide the flora of temperate salt marshes. If one seeks for any common factor in such diverse habitats the only unity appears to be in an uncertainty of water supply rather than in a general low level. The 'flowering stones' survive in South African deserts that have been known to receive rainfall only once in three years. The cactuses in their natural sites are very shallowly rooted and apparently derive water only from occasional rains which do not penetrate the desert soils to any depth. It is, in short, not possible to regard succulent plants as a single ecological or physiological type, since they associate their succulence with a diversity of other significant features.

No method is yet known by which any marked degree of succulence can be induced in a normally non-succulent species; but the degree of succulence in a susceptible species can be varied

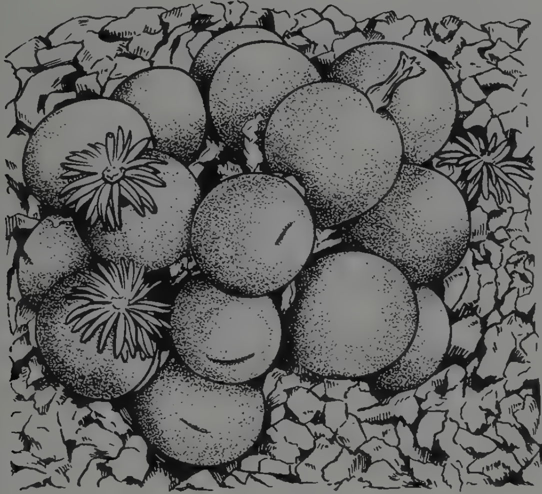

FIGURE 1 – Conophytum calculus. (*about life size*)

FIGURE 3 – Kalanchoë blossfeldiana. *Left: A long-day plant with one leaf darkened to reduce day-length. Right: A short-day plant.*

experimentally over quite a wide range. The most effective method is by the control of day-length. The crassulacean *Kalanchoë blossfeldiana* grown with days of about 12-hour illumination produces a lax habit with spoon-shaped, only slightly succulent leaves (figure 3), with a succulence ratio of 0·81. On reduction of the day length to 9 hours the leaves become smaller and much thicker, with a succulence ratio of 1·80. Internally, the change consists of an enlargement,

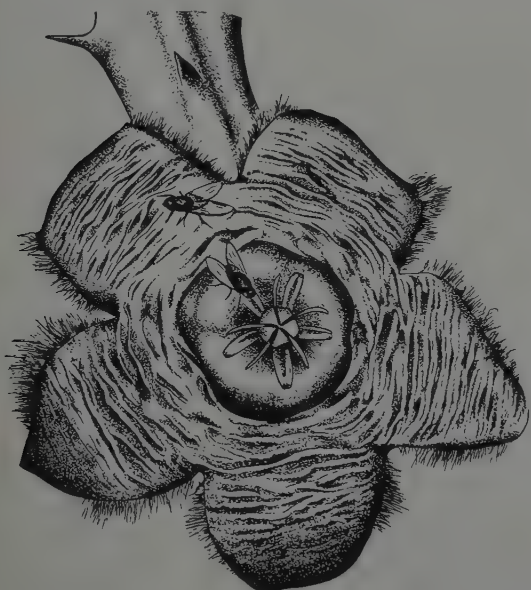

FIGURE 2 – *Flower of* Stapelia comparabilis. (*about life size*)

particularly in the transverse direction, of the leaf cells, without any considerable increase of cell number (figure 14). It has been shown that if a single leaf of a young *Kalanchoë* plant is subjected to short-day treatment, the leaves that develop vertically above it become succulent: the leaves on the opposite side of the stem retain the normal long-day characters. In this particular species increase of succulence runs closely parallel with acceleration of flowering, but the two effects can be differentiated by mild anaesthetization with chloroform. Under these conditions the acceleration of flowering is abolished but succulence is unaffected.

It would appear that succulence, like the induction of flowering, is determined by a hormone produced in young leaves and conducted upwards to the growing apex. The two effects appear, however, to be due to two different hormones, for other species, such as *Sedum kamschatkicum*, require long days for the production of their flowering hormone but retain the short-day requirement for succulence.

Succulence cannot be induced merely by the prolonged maintenance of a high osmotic pressure within the cells of a growing tissue. Nor does it appear to follow dosage with the growth hormone β-indolylacetic acid, though the effects of the hormone on cell extension have some similarities with the unidirectional type of succulent enlargement. It has been noted that although the chlorophenoxyacetic acids may induce epinasty (a rigid depression of the stalks) in *Kalanchoë* leaves, they do not increase their succulence. The hormone that induces succulence is therefore probably not an auxin.

FIGURE 4 – Anhalonium lewinii. (*about life size*)

FIGURE 5 – Astrophytum myriostigma. (*about life size*)

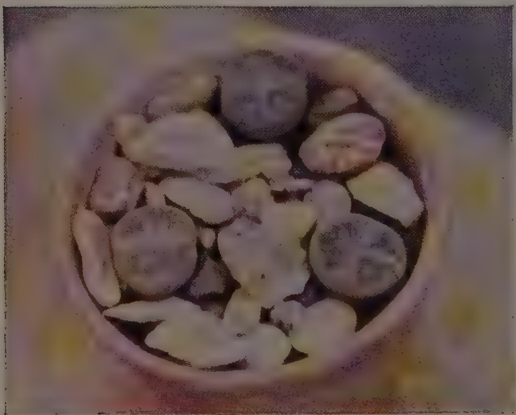

FIGURE 6 – Lithops leslei. (*about life size*)

FIGURE 7 – Kalanchoë longifolis. (*about life size*)

FIGURE 8 – Echeveria secunda. ($\times \frac{1}{5}$)

FIGURE 9 – Cotyledon agavoides. (*about life size*)

FIGURE 10 – Kleinia tomentosa. *The silvery appearance is due to the fine, closely appressed hairs. (about life size)*

FIGURE 11 – Glottiphyllum linguiforme. (× ½)

FIGURE 12 – Huernia aspera (*Asclepiadaceae*). (*about life size*)

FIGURE 13 – Sempervivum giuseppii. (× ½)

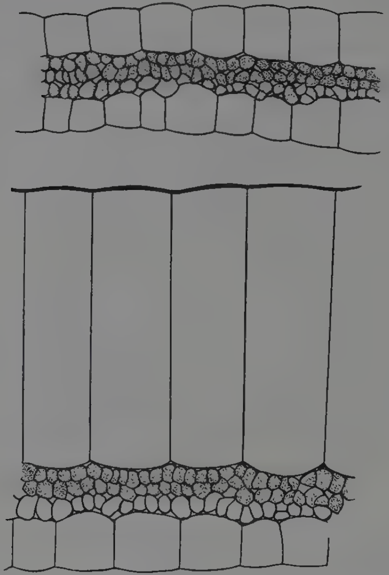

FIGURE 14 – *Transverse sections from* Tradescantia fluminensis *leaves. Top section from a normal leaf; lower section with succulence induced by lack of iron.* (× 50)

The degree of succulence may respond within limits to variations in the supply of certain nutrients, and especially to variations of the K/Ca ratio; but there is not much evidence that succulence may in some way result from a high degree of hydration of the cell colloids. The salt-succulent *Salicornia herbacea* (figure 15) considerably increases its water-content/surface ratio in specific response to the chloride ion, but the ratio is already high before any chloride is added. Significant increases of leaf water content due to chloride have been observed in the non-succulent leaves of potato plants. The causes of succulence have still to be sought among the factors determining cell growth and differentiation, and the mode of operation of the presumed succulence hormone is still quite unknown.

The consequences to a plant's way of life of a succulent habit are somewhat better understood. The most obvious are naturally the effects on its water economy: the essential point here is that succulence does not, in itself, reduce water loss. No plant cell possesses a 'diffusion pressure deficit' (defined as the depression at a given temperature of the diffusion pressure of water in a wet body below that of a flat surface of water under 1 atm. pressure) great enough to offer any serious resistance to the evaporation of its contained water. Normal leaf cells have values of a few atmospheres, which may rise to 20 atm. when the leaves are about to wilt. The diffusion pressure deficit of the air on a temperate day is of the order of 1000 atm. The great majority of succulent cells have maximal diffusion pressure deficits below 10 atm., i.e. below that of non-succulents. This difference has the important consequence that the non-succulent photosynthesizing cells (for example, those shaded in figure 14) will remain turgid, and therefore capable of maximal efficiency, until the succulent water-storage cells have been considerably depleted. It is said that the cells of succulent tissues are able to lose much more of their water without damage to themselves than is usual in other cell types. This sometimes appears to be due to an unusual degree of elasticity in the cell walls, permitting a shrinkage of 20–30 per cent of the cell volume before cell wall and protoplasm part company. This is typical of crassulacean tissues. In the Aizoaceae the walls are less elastic, but collapse into folds still adhering to the protoplasm as the cells shrink. The liliaceous succulents are reported to show a combination of the two devices.

Both succulent and non-succulent tissues alike can exist in a normal atmosphere only if they are protected by a covering having a low permeability

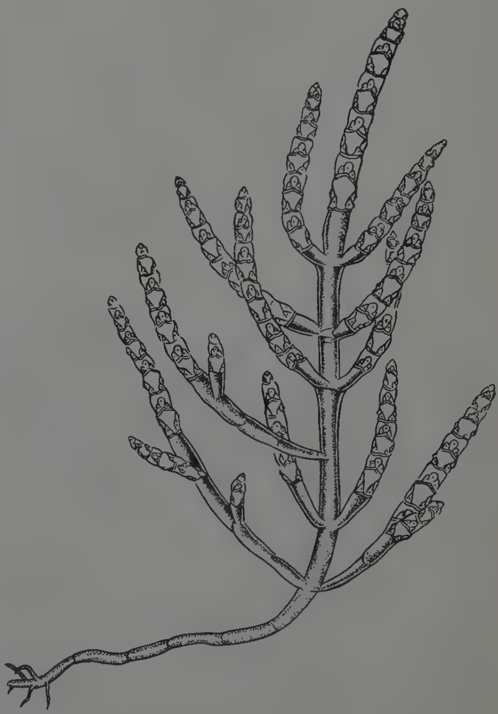

FIGURE 15 – Salicornia herbacea. (× ½)

for water, and, contrary to what is often supposed, succulent plants differ very much in this respect. The extreme succulents among the Cactaceae have thick impervious cuticles, often with a waxy bloom on the outside. Stomatal openings are comparatively sparse, and it is recorded that in American deserts they tend to shut by day and to open only at night, though this inversion of the normal rhythm does not occur in *Opuntias* grown in Britain. With the degree of surface protection they possess it is not surprising that the cacti lose water only very slowly, even under semi-desert conditions. The rate of transpiration is slow per unit of surface, and the reduction of surface that goes with the advanced succulent habit conserves their water supplies even further. It has been calculated that per unit volume of contained water *Opuntia camanchica* loses water about 1000 times more slowly than, for example, an *Impatiens noli tangere* plant.

But this situation is not general among succulent plants. The *Glottiphyllum* species (figure 11) have thin cuticles and relatively numerous stomata with a normal rhythm of opening. Their transpiration rates are much higher than those of cacti, and they become flaccid rather easily. Even the more advanced types like *Lithops* (figure 6) behave similarly in cultivation, though their behaviour in their natural desert sites is unknown. The succulents of salt marshes, such as the *Salicornia* species, also transpire rapidly and lose their turgidity easily. Their cells acquire relatively high concentrations of inorganic ions from the saline soils which may cause diffusion pressure deficits as high as 40 atm., but this is still negligible in comparison with the value of 1000 atm. for the air.

There are also very marked differences in the capacity of succulent tissues to endure water loss. Cactus stems and aloe leaves can lose 90 per cent of their water and survive. It takes months of drought to produce this condition, whereas *Stapelia* and other asclepiad stems (figure 12) and *Cotyledon* leaves lose the same proportion of their water in three or four weeks and are killed as a result.

An even more remarkable endurance is possessed by the cacti. Owing to their extremely slow transpiration rates there is no cooling effect to offset the temperature rise due to their exceptionally severe insolation. When similar temperature conditions are inadvertently produced in greenhouses the results are commonly fatal to the plants in them. In an air temperature of 31·3° C the sunny side of an *Opuntia* stem was recorded as rising to 63° C (i.e. 15–20° C above the temperature fatal for most plant tissues), without loss of turgor or other signs of damage.

It has been known for at least 150 years that succulent tissues have a marked rhythm of acidity. The acid that fluctuates most within the tissues is malic; and although much of the acid originally supposed to be malic has been proved to be *iso*-citric, this component varies relatively little. Much work and speculation have been devoted to the causes of the malate fluctuation, but it is only comparatively recently that the significant facts have been separated from the mass of data collected. Malate accumulation in crassulacean leaves is favoured by a drop of temperature to about 5° C, i.e. it must result from the adjustment of equilibria. It is accelerated by the absence of light and normally occurs during the night. It can also be accelerated by raising the external pressure of carbon dioxide to about 0·05 atm. Labelling the carbon dioxide with ^{14}C results in the rapid appearance of labelled atoms in the malic and to lesser extents in other acids within the tissues. The formation of the acids is accompanied by consumption of carbohydrates as well as of carbon dioxide, and it now seems clear that it is due to a 'dark fixation' of carbon dioxide, which in light is quenched by the more efficient photosynthesis. The carbon dioxide, once it is fixed in a carbon chain, becomes involved in the complex equilibria of intermediary metabolism: malic acid probably represents the first compound stable under cellular conditions rather than the initial fixation compound. Which of the possible paths to malic acid is most actively in operation has still to be determined.

In *Kalanchoë blossfeldiana* the amount of dark fixation that occurs is much increased by about 21 short day-lengths, and once the enhancement is induced it will continue in long days for at least a year. It has, however, been shown (in unpublished experiments by F. G. Gregory and his associates) that the enhancement of fixation of carbon dioxide does not run parallel with the induction and maintenance of either the succulence or flowering that is also caused by short-day treatment. There appears to be no essential connexion between succulence and acid-formation. Acids accumulate freely, for example, in rhubarb and sorrel leaves, which have no succulent tendencies whatever. Barley roots have been shown to incorporate $^{14}CO_2$ rapidly into malic and other acids; what appears to be characteristic of the crassulacean leaf succulents is the pronounced rhythm of formation and loss. In the succulent stems of *Kleinia articulata*, malate is lost more slowly.

Research on controlled fusion reactions

By now the main facts contained in the recent joint British and American progress reports on thermonuclear reactions will be generally known. Briefly, it has been demonstrated at three different centres that the exceedingly high temperatures theoretically necessary for thermonuclear fusion in deuterium can be produced in a pinched electrical discharge, stabilized within a toroidal vessel by an axial magnetic field. In Harwell's ZETA, for example, temperatures of the order of five million degrees have been maintained for some thousandths of a second. In SCEPTRE III at Aldermaston temperatures of 4 million degrees have been achieved. At Los Alamos the PERHAPSOTRON has maintained a temperature of 6 million degrees for about one millionth of a second. These brief periods of high temperature can be achieved as often as desired at short intervals. All the experiments show that during these periods neutrons are emitted that are very probably, though not certainly, the result of a thermonuclear reaction with an accompanying liberation of energy. It is believed that this kind of apparatus can be used to obtain substantially higher temperatures at which unequivocally thermonuclear reactions will occur. ZETA is at present being reconstructed for this purpose. The energy released increases rapidly as the temperature rises: at 25 million degrees, for example, it should be at least ten thousand times greater than at 5 million degrees. The scale of the apparatus is important, and the differences in the behaviour of these three machines are due in part at least to differences in the size of the tori. Other things being equal, it appears that the larger the torus the higher the temperature.

Even in this age of great discovery this can fairly be called a milestone in human progress. Man has achieved in the laboratory temperatures higher than that measured for the surface of any star and equal to one-third of the estimated temperature of the centre of the Sun. He has done so by processes of the kind that provide the energy of the stars. This seems, nevertheless, to be only the beginning of a completely new phase in the attainment of high temperatures in the laboratory.

The main interest in these new discoveries is the practical, and exceedingly important, one of utilizing them for the large-scale production of electrical power. At the same time, it is clear that in ZETA and similar apparatuses we have a research tool that will enormously increase our knowledge in many fields of physics and chemistry. If success in power production is attained, and there seems every reason for believing that eventually it will be, man is assured for all time of a supply of power far in excess of any demand that can at present be conceived. But how far ahead this may be is unpredictable, even by those most intimately connected with the various projects. It is certain, however, that years, and perhaps decades, must elapse before any power production on an industrial scale results.

ZETA, it must be emphasized, is an abbreviation for Zero Energy Thermonuclear Assembly: it is so named because the energy released in the supposed fusion reaction is only about one million-millionth of the energy input. For energy output and input to balance, it will apparently be necessary to reach temperatures of about 300 million degrees if deuterium is used; if it were possible to use a mixture of deuterium and tritium, however, a temperature of about 40 million degrees would suffice. The road ahead presents formidable difficulties. New methods may have to be used to heat the gas to these very much higher temperatures and to keep it there for usefully long periods, and new techniques will be required to measure the high temperatures achieved. Beyond this again lie all the tremendous engineering problems of designing and constructing the first thermonuclear power station.

But this is a prospect to fire the dullest imagination, for if success is achieved the result will benefit all mankind. At the same time there are technical difficulties clearly so great as to challange the combined scientific skill of the world. In the experiments that have lately excited so much interest there was over the last year full collaboration between Britain and the United States. But Russian scientists also have for some years past been working in the same field, and published work makes it clear that they too have made progress. There are important research centres also in Sweden, France, Germany and Japan. The International Geophysical Year has demonstrated the possibility of international scientific co-operation on a grand scale: it is very much to be hoped that the harnessing of thermonuclear power too can be achieved on the basis of truly international co-operation.

Elementary particles and space-time symmetries

A. SALAM

In recent years the number of so-called elementary particles has increased with perplexing rapidity. The purpose of this survey is to systematize, as far as possible, our knowledge in this field, following more or less the historical order of the discovery of these particles and the evolution of concepts associated with them. These concepts are emphasized because they are closely connected with the physicist's notions of the structure of space and time.

The concept of an elementary particle has arisen from man's age-old search for the ultimate, fundamental, and indivisible units of which matter is composed. The nineteenth-century chemist came very near to the end of this quest with the realization, on the basis of the periodic table of the elements, that all matter, of whatever form, was made from 92 different types of atoms. With the work of J. J. Thomson and Rutherford at the beginning of this century came the belief that all these 92 different types of atoms were themselves made from just two elementary particles, the electron and the proton. These are stable, indivisible particles with unique masses and have the following properties:

1. The electron is a very tiny chunk of matter, with a mass of 10^{-27} g; the proton has a mass some 2000 times greater.
2. The electron carries a negative charge of about 10^{-10} e.s.u.; the proton a positive charge of exactly the same magnitude.

The work of Planck and Einstein soon added to this list a third elementary particle, the photon. They recognized that the radiation energy of an electromagnetic field exists in the form of discrete units, which were called photons. On this view, a beam of light consists of a stream of photons, all travelling with the same velocity.

The electron, proton, and photon interact with each other in the following manner:

1. According to Maxwell's classical theory, all charged particles emit or absorb electromagnetic radiation when accelerated: according to Planck and Einstein's view, electromagnetic radiation exists in the form of photons. This means that electrons or protons emit or absorb photons. Figure 1 is a space-time picture of this emission or absorption process. On the right, an electron (solid line) is emitting a photon (dotted line); on the left, an electron absorbs a photon.

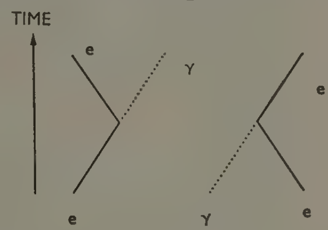

FIGURE 1

2. According to Maxwell's theory, one charged particle attracts or repels another charged particle by first producing an electromagnetic field in the surrounding space, and this field in turn acts on the second charged particle. On this present view this is visualized as an emission of one (or many) photons from one electron and reabsorption by the second (figure 2).

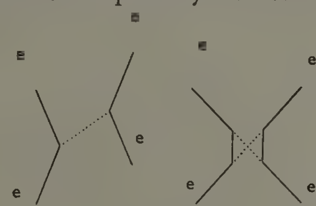

FIGURE 2

3. The emission or absorption of photons and their exchange between two electrons or an electron and proton must proceed in accordance with what are called conservation laws. These require that:
   (i) In any physical process, (*a*) the total charge Q, (*b*) the number of electrons N_e, and (*c*) the number of protons N_p must be the same before and after the interaction.

The number of photons at the beginning, however, can be different from that at the end.

(ii) In any process, (*a*) the total energy E, (*b*) the total momentum P, and (*c*) the total angular momentum J of all the particles must remain the same before and after the interaction.

These so-called conservation laws are experimental. They can, however, readily be linked with ideas about the structure of space-time. One can show that saying that momentum and energy are conserved is equivalent to saying that the results of an experiment are independent of where in space and when in time it is performed. This is the principle of translation symmetry of space-time. It can also be shown that saying that angular momentum is conserved is equivalent to saying that the results of an experiment do not change if the entire experimental set-up is rotated through any angle. This is the principle of rotation symmetry of space.

To give a precise meaning to the concept of conservation of angular momentum, it was found necessary to assign an intrinsic angular momentum (spin) to every elementary particle. Specifically, one has to ascribe a spin of 1 unit to the photon and a spin of $\frac{1}{2}$ unit to the electron and to the proton. To fix one's ideas about intrinsic spin one may roughly conceive of an electron (or a proton) as a spinning top. If the electron is moving, its axis of spin may, to take a special case, be along the direction of motion. In that case, the spin may appear clockwise or counter-clockwise to someone looking along the forward path of the particle. In other words, the electron may move and spin like a right-hand screw (right-polarized electrons) or like a left-hand screw (left-polarized electrons). In a beam of free electrons, half will be right-polarized and half left-polarized (figure 3).

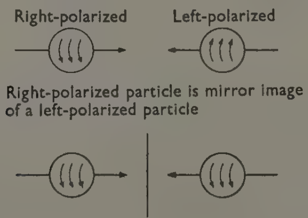

FIGURE 3

Clearly, a right-spinning or a right-polarized electron is a mirror image of a left-spinning or a left-polarized electron. This important point will be referred to later.

To these conclusions about space-time structure P. A. M. Dirac's work carried out during 1928 [1] added a new and deep concept, for he could show on general grounds that all particles in nature must exist in pairs. To every particle there corresponds an anti-particle of precisely the same mass and spin, but of opposite charge. Thus the existence of the negative electron implies the possible existence of a positive anti-electron (the so-called positron); if the proton exists, so must an anti-proton. From the existence of the hydrogen atom we may infer that an atom of anti-hydrogen can exist with precisely the same energy levels.

Further, Dirac showed that when a particle and anti-particle collide both disappear, their energy, momentum, and angular momentum going into photons. Conversely a photon, under suitable circumstances, can produce a pair consisting of a particle and an anti-particle. Figure 4 gives a

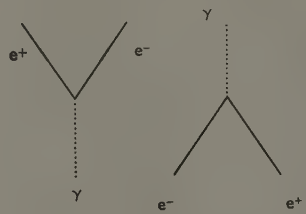

FIGURE 4

space-time picture. On the right, a photon produces a pair consisting of an electron and a positron. On the left, an electron-positron pair disappears with the emission of a photon. To take account of this we must modify two of our conservation laws, namely that $\mathcal{N}_e$ = constant and $\mathcal{N}_p$ = constant, to read $\mathcal{N}_e - \mathcal{N}_{\bar{e}}$ = constant and $\mathcal{N}_p - \mathcal{N}_{\bar{p}}$ = constant. Here $\bar{e}$ denotes positron, $\bar{p}$ anti-proton, etc.

This work of Dirac was among the most momentous in the history of physics. It revealed a deep symmetry in nature. It provided a mechanism by which electron-positron pairs could be created or annihilated. Not long after Dirac's work came the brilliant experimental confirmation of pair-creation by photon showers from C. D. Anderson and P. M. S. Blackett. Figure 5 shows photons passing through a lead plate: being uncharged, they leave no tracks. One can, however, see pairs of oppositely charged particles simultaneously created, curving to the right and left in a magnetic field applied to the chamber in a direction normal to the plane of the paper.

Recapitulating, at this stage we have considered five elementary particles: the photon, the positive

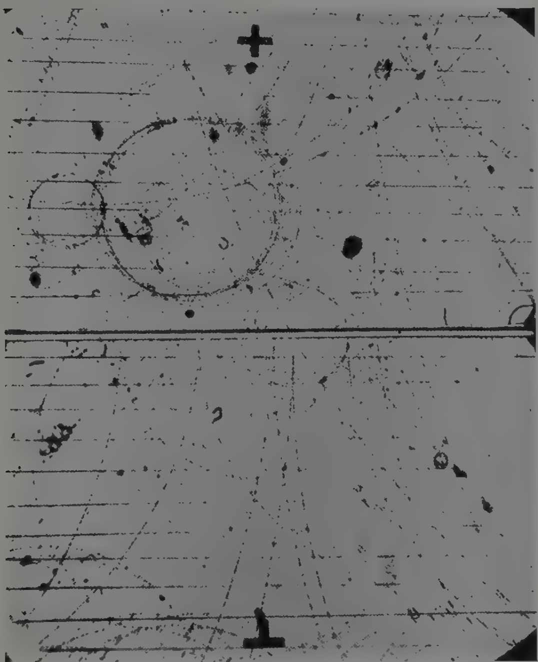

FIGURE 5 – *A shower of protons passing through a lead plate produces electron–positron pairs in the lower part of the cloud-chamber.*

and the negative electron, and the positive and the negative proton. The electron-electron or electron-proton force can be understood completely on the basis of the charge on these particles and an exchange of photons between them.

The next development in the subject came with the realization that the proton-proton force is only partly explained by the above picture. When two protons are close to each other by less than 10^{-13} cm, a much stronger force arises between them, the so-called nuclear force. This force is stronger than the electromagnetic force, produced by exchange of photons, by a factor of 100. At about the same time came the discovery of the neutron—our sixth elementary particle—and realization that all atomic nuclei contain about as many neutrons as protons. The neutron is about as massive as the proton, but differs from it in being chargeless. To a very good approximation the proton-neutron force is equal to the proton-proton force. The neutron and the proton could in fact be considered two states, chargeless and charged, of the same basic particle.

The neutron was destined to enrich the concepts in the subject in a very surprising way. It is slightly heavier than the proton, and in about twelve minutes a free neutron decays into a proton and an electron. In this decay the total energy, momentum, and angular momentum before and after the decay did not seem to balance. Here indeed was a searching test of the theoretical physicist's faith in the concepts he had himself created. If one gave up the demand that these conservation laws should hold, one would have to revise one's ideas about the structure of space-time. To resolve this dilemma W. Pauli suggested that in neutron decay a further neutral particle of zero rest-mass must be emitted which carries away the missing energy, the missing momentum, and the missing angular momentum. This particle was called the neutrino. The discovery of the neutron thus introduced two new elementary particles, the neutron itself and the neutrino.

But is the neutron an elementary particle? The particles we have dealt with so far, the electron, the proton, the photon, and even the neutrino, are all stable, indivisible particles. This is not true of the neutron. To be sure, on the nuclear time scale the neutron decay is a very slow process. The other types of process we have considered, such as photon absorption and emission, take place in about 10^{-19} second. On this time scale neutron decay is certainly very slow. Nevertheless, the fact of the decay remains and forces us into the following compromise. We must divide all fundamental interactions into three classes:

1. Nuclear interactions, which give rise to p–n, p–p, and n–n forces. These interactions are the strongest we know of in nature.
2. Electromagnetic interactions, which give p–e and e–e forces. These are medium strong.
3. Weak interactions, which are responsible for the decay of the neutron.

The relative strengths of these interactions are in the ratio of $1 : 10^{-2} : 10^{-12}$. To the extent that the weak interactions can be neglected, the neutron is elementary, stable, and indivisible. To the extent that the electromagnetic interaction can be neglected the neutron and the proton are identical. Thus all the particles we have considered are elementary, but some are more elementary than others.

Our survey has now brought us to 1935, when H. Yukawa [2] started to ponder over the problem of the specifically nuclear force. We have seen that the electromagnetic interaction of charged particles can be represented as arising from exchange of photons. Yukawa argued that, in complete analogy with this, the proton-neutron force must also be produced by an exchange of some

new type of particles, which he called mesons. From the characteristics of the nuclear forces Yukawa deduced that:

1. Mesons must possess mass. They ought to be about 300 times as massive as electrons.
2. Unlike photons, mesons may be charged or neutral.
3. Like photons, mesons should be emitted or absorbed singly by the protons or the neutrons.
4. In suitable circumstances one such particle could create a proton–anti-proton or neutron–anti-neutron pair. Conversely, nucleons and anti-nucleons would annihilate each other, the energy and momentum going into mesons (figure 6).

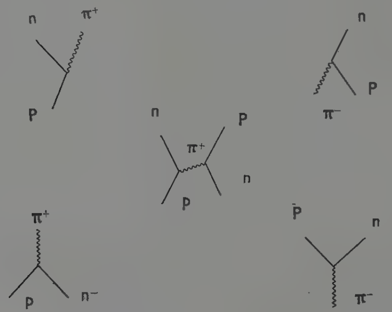

FIGURE 6 – *Solid lines represent protons or neutrons; wavy lines represent mesons. Notice the similarity of meson-nucleon interactions to photon-electron interactions in figures 1 and 2.*

The experimental discovery of mesons by C. F. Powell in 1947 forms part of the exciting annals of physics. The Yukawa particles are nowadays called π-mesons (π^+, π^0, π^-, according to charge) (figure 7).

Considering the strong interactions in more

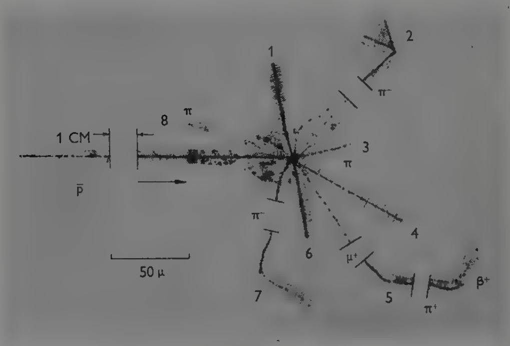

FIGURE 7 – *Example of* $\bar{\text{p}} + \text{p}$ *collision. A number of* π-*mesons are produced.*

detail, at this stage the nuclear force arises between the two nuclear particles (p, n) and the three π-mesons (π^+, π^0, π^-). As remarked before, the nuclear force is much stronger than the electromagnetic. Thus to one part in a hundred, charge on a particle is irrelevant in considering reactions within the nucleus. To a very good approximation, then, the proton and the neutron are identical particles, as also are the three π-mesons. The fact that there are three π-mesons equivalent to each other immediately suggests that we should formally treat these three as components of a vector in a three-dimensional space. To distinguish between this abstract space and ordinary space we call this new space the isotopic space. The equivalence of the three π-mesons is then formally stated as the consequence of rotation symmetry in the isotopic space. As previously noted, rotations are connected with angular momentum, and we can, analogously with ordinary space, assign an intrinsic isotopic 'spin' I_z to π-mesons. On this basis π^+ corresponds to $I_z = 1$; π^0 to $I_z = 0$; π^- to $I_z = -1$. Applying the analogy to the nucleon, which exists in two equivalent states (the proton and the neutron), we may assign $I_z = \frac{1}{2}$ to the proton and $I_z = -\frac{1}{2}$ to the neutron. Just as in ordinary space rotation symmetry implies conservation of angular momentum, so in isotopic space, rotation symmetry implies conservation of isotopic spin.

In any nuclear interaction, then, not only energy, momentum, and angular momentum, but isotopic spin should be conserved. But there is one important difference between this new conservation law and the other conservation laws. Clearly the electromagnetic interaction, in so far as it distinguishes charged particles from neutral particles, violates rotation symmetry in this space, and thus the law of conservation of total isotopic spin is only approximate.

Three new particles have now been added to our list. The same question as for the neutron arises again. Are these stable particles? The answer is no, and the decay of all these three particles presents novel features.

Consider π^- first. One might have expected that this particle would decay into an electron and a neutrino. A π^- could convert virtually into an anti-proton neutron pair, and this pair would then disappear, giving an electron and a neutrino. For some very inexplicable reason this does not happen. Instead, nature completely confounds us. The π-meson decays into a new particle, called the μ-meson, and a neutrino. This new particle,

the μ-meson, is about 200 times as heavy as the electron. The strength of this decay interaction is identical with the interaction responsible for neutron decay (figure 8).

The π-meson mystery does not stop here. In about 10^{-6} second the μ-meson itself spontaneously decays into an electron and two neutrinos. Quantitatively, once again it seems to be the same interaction as is responsible for the π-decay. Without hesitation one may say that the μ-meson is the most mysterious particle in physics. We do not know any good reason why it should exist, nor do we know why it should have such a large mass.

So far we have considered developments before 1947. In the last few years. following a brilliant discovery by C. C. Butler and G. D. Rochester,

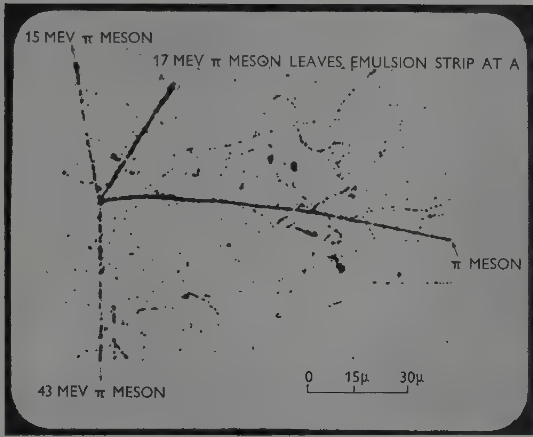

FIGURE 9 – *Example of K-decay*, $K^+ \rightarrow \pi^+ + \pi^+ + \pi^-$.

FIGURE 8 – *Two examples of the successive decay* $\pi \rightarrow \mu \rightarrow e$.

eight new particles have been discovered, and we must now consider these. They fall into two distinct categories:

1. There are six particles, each heavier than the proton, and designated Λ^0, Σ^+, Σ^-, Σ^0, Ξ^0, and Ξ^-. These all decay into a proton or a neutron, the decay strengths again being quantitatively the same as are those responsible for n, $\pi^{\pm}$, and $\mu^{\pm}$ decays. Since a proton or a neutron is one of the end products in the decay, there still is a conservation law for heavy particles. It now, however, reads $\mathcal{N}_p + \mathcal{N}_n + \mathcal{N}_\Lambda + \mathcal{N}_\Sigma + \mathcal{N}_\Xi - (\mathcal{N}_{\bar{p}} + \mathcal{N}_{\bar{n}} + \mathcal{N}_{\bar{\Lambda}} + \mathcal{N}_{\bar{\Sigma}} + \mathcal{N}_{\bar{\Xi}}) = \text{constant}$, where $\mathcal{N}$ is the number of particles of the type designated by the subscript.
2. There are also particles, with masses intermediate between the nucleon and the π-meson, which finally decay into electrons and neutrinos. These are the K^+ and K^0 particles (figure 9).

These eight particles presented certain unexpected features and for a number of years were called 'strange' particles. From the copiousness of their production it seemed clear that their mutual interactions were strong in our technical sense. We have seen that isotopic spin is the distinguishing feature of strong interactions. It seemed appropriate to assign to these particles isotopic spin values and to demand that in their interactions isotopic spin conservation should hold. This assignment was made partly on theoretical and partly on phenomenological grounds by M. Gell-Mann and K. Nishijima [3, 4] in 1953. The results were indeed startling. Some of these are:

1. In any collision process involving π-mesons and nucleons, not only can these 'strange' particles be produced, but there must always be at least two of them. For example, $\pi^- + p \rightarrow \Sigma^- + K^+$.
2. In this same collision it is possible to produce $\Lambda^0 + K^0$, $\Sigma^0 + K^0$, or $\Sigma^- + K^+$, but never $\Sigma^+ + K^-$, even though the total charge, the heavy particle number, etc., all balance on both sides of the reaction. The explanation of this in terms of isotopic-spin conservation law is immediate. We notice from the table that the total I_z value for $\pi^- + p$ is $-1 + \frac{1}{2} = -\frac{1}{2}$. For $\Sigma^- + K^+$, for example, it is also $-1 + \frac{1}{2} = -\frac{1}{2}$. For $\Sigma^+ + K^-$, however, $I_z = +\frac{1}{2}$, and thus this reaction cannot take place. A Pythagorean at this stage may well exclaim 'Number rules the Universe'. As with the former predictions cited, every one of the predictions made by the Gell-Mann-Nishijima theory has been verified (figure 10).

To summarize all our findings:

1. Strong interactions take place between p, n, Λ^0, $\Sigma^{0\pm}$, Ξ^{0-}, $\pi^{0\pm}$, $K^{0\pm}$. These are characterized by the following set of conservation laws (Table I):

FIGURE 10 – *Associated production:* $\pi^- + p \rightarrow \Lambda^0 + K^0$ *Tracks 1a, 2a are* p *and* π^- *from* Λ^0 *decay; tracks 1b, 2b are* π^+, π^- *particles from* K^0 *decay.*

(i) Conservation of charge Q.

(ii) Conservation of heavy particle number
$$\mathcal{N}_p + \mathcal{N}_n + \ldots - (\mathcal{N}_{\bar{p}} + \mathcal{N}_{\bar{n}} \ldots) = \text{constant}$$

(iii) Conservation of energy momentum. Space-time translation symmetry.

(iv) Conservation of spin. Space-time rotation symmetry.

(v) Conservation of isotopic spin. Isotopic space rotation symmetry.

(vi) Particle–anti-particle symmetry.

Subject to these rules, any interaction that can take place does take place.

2. Medium strong interactions involve electromagnetic interaction of all charged particles p^+, $\Sigma^\pm$, $\Xi^\pm$, $\pi^\pm$, $e^\pm$, $\mu^\pm$. These interactions are responsible for π^0 and Σ^0 decay in times $\sim 10^{-17}$ seconds. The conservation laws are the same here, save for (v).
3. Weak interactions, which are responsible for the spontaneous decay of all particles except p, e, ν, and the photon. The conservation laws are again (i) to (vi) except for (v), which is peculiar to the strong interaction.

We now come to the most recent act in our drama, bringing us up to January 1957. I have mentioned the translation and rotational symmetries of space-time. I have omitted to mention two further symmetry properties associated with space-time, namely space-reflection symmetry and time-reflection symmetry.

Consider space reflection or mirror reflection first. Since in a mirror a right hand reflects as a left hand, space-reflection symmetry is the same as right-left symmetry. The concept that right and left are indiscernible dates back to Leibniz, who first gave it a precise formulation. From Leibniz's day up to January 1957 it was accepted that there is no inner difference between right and left. Before proceeding, let me state the precise form in which the law of space reflection had been formulated. Just as Dirac showed that for any particle there must exist an anti-particle, so the law of space reflection asserts that if a particle exists the one obtained by reflecting it in a mirror must also exist. If a reaction can take place, the corresponding reaction seen in a mirror is also a physically possible one. Thus if right-polarized neutrinos can exist, so also must left-polarized neutrinos. Just as space-time rotation symmetry leads to conservation of spin, space-reflection symmetry leads to conservation of what is known as 'parity'.

The space-reflection symmetry or parity conservation principle is philosophically appealing. Even more important than any philosophical argument, the principle is known to hold for all strong and electromagnetic interactions. In the summer of 1956 C. N. Yang and T. D. Lee [5] pointed out that there had until then been no experiment to prove or to disprove it for weak interactions, and they suggested a number of experiments which might clinch the matter. So firm was the belief that the principle must hold for all interactions that W. Pauli wrote to V. Weisskopf on 17th January, 1957: 'I do *not* believe' (the *not* is heavily underscored by the writer) 'that the Lord is a weak left-hander, and I am ready to bet a very high sum that the experiments will give symmetric results.'

The experiments were completed two days after Pauli wrote. They have since been repeated all over the world. They showed unequivocally that in weak interactions there is no right-left symmetry. More precisely, the experiments showed that right-polarized neutrinos exist but left-polarized neutrinos do not. On reflecting a neutrino in a mirror one sees nothing.

It is sobering to think that the experimental results could have been discovered ten years back, for the evidence existed on all the photographic plates recording π^+ and μ^+ decay (figure 8; both photographs are pre-1948). If reflection symmetry holds, relative to the direction of motion of μ-mesons, the same number of electrons should be emitted in the forward as in the backward direction. If anybody had bothered to count the numbers he would have discovered the asymmetry. On January 27th, 1957 Pauli wrote:

'Now after the first shock is over I begin to collect myself. Yes, it was very dramatic. On Monday, the 21st, at 8.00 p.m. I was supposed to give a lecture on the neutrino theory. At 5.00 p.m. I received 3 experimental papers. . . . I am shocked not so much by the fact that the Lord prefers the left-hand but by the fact that he still appears to be left-right symmetric when he expresses himself strongly. In short the actual problem now seems to be the question why are strong interactions right and left symmetric.'

Explaining to a classicist friend the magnitude of the revolution that had occurred in physics, I asked him if any classical writer had ever considered giants with only the left eye. He confessed that one-eyed giants have been described, and he supplied me with a full list of them; but they always sport their solitary eye in the middle of the forehead. In my view, what we have found is that space is a weak left-eyed giant.

One can perhaps give the deeper reason [6] why right-left symmetry should be violated whenever a neutrino is emitted. It can be shown that an exactly zero mass for the neutrino is incompatible with right-left symmetry. We have lost the symmetry principle, but perhaps gained an exactly zero mass for the neutrino. Today the gain seems unimportant compared with the loss, but a few years hence we may think differently.

The time-reflection principle asserts symmetry between past and future; in our formulation it does not make statements about causation but

TABLE I

Comparison of strong, electromagnetic, and weak interactions

	STRONG (10^{-22} sec) $p, n, \Lambda, \Sigma, \Xi, \pi, K$	ELECTROMAGNETIC (10^{-18} sec) $p, \pi^{\pm}, \Sigma^{\pm}, K^{\pm}, \Xi^{-}, e^{\pm}, \mu^{\pm}, \gamma$	WEAK (10^{-10} sec) $n, \pi, \mu, \Lambda, \Sigma, \Xi, K$ decay
1. Charge conservation	✓	✓	✓
2. Heavy particle conservation	✓	✓	✓
Space-time			
3. Translation symmetry	✓	✓	✓
4. Rotation symmetry	✓	✓	✓
5. Space-reflection symmetry	✓	✓	×
6. Time-reflection symmetry	✓	✓	?
7. Isotopic space rotation symmetry	✓	×	×
8. Particle–anti-particle symmetry	✓	✓	×

TABLE II

Elementary Particles (1958)

Particle		Rest mass	Spin	I_z	Decay time (sec)	Decay products	Anti-particle
1.	γ	0	$+1$		∞	Stable	γ
2.	e^-	1	$\pm\frac{1}{2}$		∞	Stable	e^+
3.	μ^-	207	$\pm\frac{1}{2}$		10^{-6}	$e^- + \nu + \bar{\nu}$	μ^+
4.	ν^0	0	$+\frac{1}{2}$		∞	Stable	$\bar{\nu}$(spin $-\frac{1}{2}$)
5.	p^+	1836	$\pm\frac{1}{2}$	$\frac{1}{2}$	∞	Stable	$\bar{p}$
6.	n^0	1839	$\pm\frac{1}{2}$	$-\frac{1}{2}$	10^3	$p + e^- + \bar{\nu}$	$\bar{n}$
7.	Λ^0	2180	$\pm\frac{1}{2}$	0	10^{-10}	$p + \pi^-$ or $n + \pi^0$	$\overline{\Lambda}^0$
8.	Σ^+	2331	$\pm\frac{1}{2}$	1	10^{-11}	$p + \pi^0$ or $n + \pi^+$	$\overline{\Sigma}^+$
9.	Σ^0	2331	$\pm\frac{1}{2}$	0	10^{-18}	$\Lambda^0 + \gamma$	$\overline{\Sigma}^0$
10.	Σ^-	2345	$\pm\frac{1}{2}$	-1	10^{-10}	$n + \pi^-$	$\overline{\Sigma}^-$
11.	Ξ^0	2590	$\pm\frac{1}{2}$	$\frac{1}{2}$	10^{-10}	$\Lambda^0 + \pi^0$	$\overline{\Xi}^0$
12.	Ξ^-	2590	$\pm\frac{1}{2}$	$-\frac{1}{2}$	10^{-10}	$\Lambda^0 + \pi^-$	$\overline{\Xi}^-$
13.	π^+	273	0	1	10^{-8}	$\mu + \nu$	$\pi^-(I_z = -1)$
14.	π^0	264	0	0	10^{-16}	2γ	π^0
15.	K^+	966	0	$\frac{1}{2}$	10^{-8}	$\mu + \nu$, 2π, 3π	$K^-(I_z = -\frac{1}{2})$
16.	K^0	966	0	$-\frac{1}{2}$	10^{-10}	$\pi^+ + \pi^-$ or $\pi^0 + \pi^0$	$\overline{K}^0(I_z = +\frac{1}{2})$

merely such statements as that: The number of K's and Σ's produced in $\pi^- + p$ collision is the same as the number of $\pi^- + p$ produced in K, Σ collision. It is known that the principle holds in strong interactions. We strongly suspect that it also holds for electromagnetic interactions. There is no experiment yet to test it for weak decays. One may remark that if the principle holds in weak decays, the left-eyed giant, on looking into a mirror, will see not a right-eyed giant but a right-eyed anti-giant.

DISCUSSION

The entire development presented here is based on the assumption that the structure of space and time is that given by the special theory of relativity. The reason for ignoring the general theory of relativity is that the gravitational force is an even weaker one than any that have been considered. It has a strength of 10^{-34} in the units used above, and to an excellent approximation its effects can be neglected.

Turning to some of the problems in the physics of elementary particles, we ask why there are just these particles. Are there still more particles to be discovered? In the case of particles possessing strong interactions we believe we understand the deeper reason for their existence in terms of the isotopic spin space. Why this space exists we do not know; but, granted its existence, it would seem that we have already discovered all particles possessing strong interactions, except possibly for one particle. This is a rash statement. Such statements have been made again and again in the history of physics and have always proved false, and I must qualify it by saying that the isotopic group may admit other particles, but they will all probably have lifetimes shorter than 10^{-19} second.

We still do not know the deeper symmetry principle associated with particles falling in the electromagnetic and weak interaction categories. There may well, for example, be more companion particles of the μ-meson. In fact, all we know about the particles that fall in these two categories is that their interactions violate some of the strong interaction symmetries. These interactions seem in a sense to have a negative role. There must in nature be a hierarchy of symmetry principles, some of which are dearer to nature's heart than others.

All our remarks on whether further particles are likely to be discovered or not depend, of course, on whether there exist further categories of interactions besides the three mentioned. If there do, naturally there will be whole classes of new particles. This question is connected with the existence of conservation laws. So far, we believe that four conservation laws hold universally. Are there

further interactions weaker still, for which these also break down? Cosmologists in their theories of continuous creation have already suggested that energy and momentum are indeed not conserved when the still weaker gravitational interaction is considered. From the present point of view this hypothesis becomes entirely plausible.

On looking through the table of elementary particles there is only one thought in my mind: how deeply privileged our generation is to have been presented with this fascinating challenge. People speak of the multiplicity of elementary particles—they even give them outlandish names like 'strange' particles; they shake their heads in disapproval of 'weak' laws. I believe these are but stepping stones to an inner harmony, a deep pervading symmetry. The μ-meson may seem out of place today. When we discover its real nature we shall marvel how neatly it fits into the Great Scheme, how integral a part it is of something deeper, more profound, more transcending. Faith in the inner harmony of nature has paid dividends in the past. I am confident it will continue to do so in the future.

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Book reviews

QUATERNIONS

Five Mathematical Structural Models, *by Otto F. Fischer. Pp. vi* + 412. *Axion Institute, Stockholm.* 1957. $10 *net.*

The purpose of this book is to illustrate the use of quaternions in the various branches of mathematical physics. The author shows how well they are adapted for the discussion of Maxwell's equations, but the reviewer must confess that when it comes to an application to the theory of elasticity he is inclined to think that the analysis is clearer when expressed in the customary tensor notation. There are other interesting applications to wave mechanics, to quantum theory, and to Hamilton's optics. The book is a little difficult to read, partly because it is reproduced by the rotaprint process and partly because there are so many diacritical signs attached to the symbols for the quaternions. There is an impressive list of references, but it does not include the pioneer work on quaternions by McAuley. G. TEMPLE

DYNAMIC INSTABILITY

Dynamic Instability, *by Y. Rocard. Translated from the French by M. L. Meyer.* Pp. *xi* + 227. *Crosby Lockwood & Son Ltd.*, London. 1957. 45s. *net.*

University lecturers and experts in industry will welcome the English translation of this excellent work. Anyone who requires a general introduction to the field of dynamic instability will find this developed in a very logical manner and amply illustrated with a number of highly topical problems.

The criterion for instability is derived for examples with two degrees of freedom. When two separate oscillating systems, each with its own natural frequency, are coupled together by a spring, two new frequencies of oscillation arise. The difference between these new frequencies is always greater than the difference between the original frequencies. Such a coupled system is conservative and stable, and always obeys the Lagrange equations. Introduction of external forces independent of elastic potential but in phase with either the displacement or the acceleration vectors, i.e. a feedback of energy, reduces the difference between frequencies of coupled systems. Instability is imminent when these frequencies become equal. The whole book is based on this theorem, which is derived most lucidly for simple systems and applied in detail to the stability calculations for motor cars, including wheel shimmy and, for aircraft, wing flutter and longitudinal motion. The problem of self-excited oscillations due to wind forces of suspension bridges is dealt with in great detail (about half the book is devoted to this), with particular reference to the Tacoma Narrows Bridge. The book is well produced, and the index would appear to be adequate.

P. GROOTENHUIS

QUANTUM MECHANICS

Quantum Mechanics, *by H. A. Kramers. Pp. xvi* + 496. *North-Holland Publishing Co., Amsterdam.* 1957. *Fl.* 45 *net.*

We are told that the frontiers of science advance at an ever-increasing rate. It is therefore reassuring to find an account of the fundamentals of quantum mechanics written in 1937, which is as readable now as it must have been then—and almost as up to date. The author has a most intriguing way of easing rather than plunging the reader into the intricacies of the subject, and nothing of this is lost in a most English translation into English. The book is sprinkled with original proofs and delightful asides. An example of the former is the proof of the existence of the energy eigenvalues of the Schrödinger equation, of the latter the remark on the thorny problem of the connection of spin and statistics that 'the argument is not rigorous but contains some grains of truth'.

Where the book tends to date is in its treatment of quantum electrodynamics. This subject has changed so radically in the post-war years that any pre-war treatment of it looks decidedly clumsy. Quantum electrodynamics has long lost its 'preliminary character', and a footnote referring to Thirring's book, published in 1955, is ingenuous rather than helpful. But this is a splendid book, and English physicists owe

much to Dr ter Haar for undertaking the selfless task of translation.

L. R. B. ELTON

PIEZOELECTRICITY

Piezoelectricity. *Pp. x* + 369. *Her Majesty's Stationery Office, London.* 1957. 75*s. net.*

This is the first of the Selected Engineering Reports of the Post Office Research Station and comprises eleven papers on certain aspects of piezoelectricity important in the design of crystal oscillators, resonators and similar electro-acoustic devices. R. Bechmann, a prominent worker in this field, was responsible for most of the work described.

The first four papers treat theoretically the fundamental relationships between the elastic and the electrical properties of crystals and the determination of the relevant constants. Other papers describe practical measurements of the constants of several water-soluble piezoelectric crystals, and there is an interesting account of the growth and cutting of large artificial crystals.

This is a book for the specialist. It brings together much information at present scattered throughout the literature and provides a handy reference source for the research worker engaged in the crystal vibrator field. The earlier papers can be read with profit by those interested in the theoretical aspects of piezoelectricity; the treatment is lucid and refreshing and is as simple as this difficult subject permits.

It is a pity that the summary of the published data on piezoelectric materials does not include some of the recent piezoelectric materials now in demand.

H. J. H. STARKS

ION-EXCHANGE RESINS

Ion-Exchange Resins, *by J. A. Kitchener. Pp. vii* + 109. *Methuen & Co. Ltd., London; John Wiley & Sons Inc., New York.* 1957. 9*s.* 6*d. net.*

This is the latest of the Methuen Chemical Monographs, and it maintains in every way the high standards of this series.

The book is intended to be a concise introduction to the theory and general fundamentals of ion-exchange resins, and in this it succeeds admirably. Unlike the majority of books on ion exchange, it is not overburdened with literature references, and there are merely a few selected 'key' references at the end of each chapter. These are thoroughly up to date: over three-quarters of them are subsequent to 1952, while one is as recent as 1957.

The book begins with a brief account of the discovery of the phenomenon of ion exchange and the development of exchangers from the inorganic silicate materials to the resins. The fundamental physical chemistry of exchange equilibria and kinetics follows, and a few selected applications of the resins are then given. The final chapter describes some recent developments, including highly selective and redox resins and ion-exchange resin membranes. The style is flowing and is distinguished by a complete absence of padding. There is in consequence a vast amount of information concentrated into the 100-odd pages.

The subject matter is pitched at just the right level to be understood by the newcomer and yet it is thoroughly readable by those already working in the field. To those in both these categories the book can be highly recommended.

R. E. KRESSMAN

TOXIC PHOSPHORUS AND FLUORINE COMPOUNDS

Phosphorus and Fluorine. The Chemistry and Toxic Action of their Organic Compounds, *by B. C. Saunders. Pp. xv* + 231. *Cambridge University Press, London.* 1957. 32*s.* 6*d. net.*

This monograph stems from wartime research on toxic compounds containing phosphorus and fluorine, in which the author played a leading part. His subject has now, however, a much wider interest, for many compounds of the types discussed are of great value in pest control, and a few have applications in the field of clinical medicine. Not least, work on the mode of toxic action of these substances has resulted in important advances in our knowledge of enzyme systems.

The chemical sections of the book describe the preparation and reactions of various groups of toxic compounds in which the author has been interested. Chief among these are the fluorophosphanates, or phosphofluoridates as they are now more usually called, and fluoracetates, together with numerous substances related to them. No attempt has been made to cover the field completely, however, and it would have been impossible to do so in a book of this size. Instead the author has sought to discuss in some detail the more biological aspects of his subject. This he is well qualified to do, and it is this dual approach that gives the book its special value. The non-specialist reader is given a general account of the mammalian nervous system and then of current ideas on enzyme activity and inhibition. The result of this new approach is a book that can be given an unqualified recommendation. It will interest not only chemists, but also many biologists who are concerned with the problem of enzyme inhibition.

H. J. EMELEUS

CHEMISTRY OF THE ACTINIDE ELEMENTS

The Chemistry of the Actinide Elements, *by J. J. Katz and G. T. Seaborg. Pp. xv* + 508. *Methuen & Co. Ltd., London; John Wiley & Sons Inc., New York.* 1957. 63*s. net.*

The actinide elements include all the nuclear fuels and fuel precursors of atomic energy. It is most valuable, therefore, to have this comprehensive and authoritative account of their chemistry from distinguished members of two of the principal centres where they are studied. It will to a large extent replace the earlier volume affectionately known as '14A' in the American National Nuclear Energy Series, which has by now become somewhat out of date. The new book is up to date enough to include a passage on nobelium, element 102, which was discovered last spring.

There is an astonishing amount of information packed into the book, often in tabular form. The authors have been most successful, too, in summarizing the varying views on issues still in doubt.

The plan of the book, after a brief introduction, is to consider the elements in order, chapter by chapter, starting with actinium. For each element there is a brief historical account; a survey of its isotopes; a section on its natural occurrence (where appropriate); a fairly full description of methods of extraction or preparation and purification, including industrial processing; and finally an account of its chemistry. The last, long chapter of the book summarizes and correlates properties throughout the actinide series.

In a sense, the actinides are treated as if they were ordinary, non-radioactive chemical elements, for there is very little on radiochemical techniques, other than a couple of pages and four photographs in the introduction, dealing with problems of handling. The omission is obviously deliberate, to keep the book within reasonable limits.

The book is well printed, gives full references, and has a comprehensive index. H. A. C. MCKAY

ORGANIC CHEMISTRY

Tetrahedron. The International Journal of Organic Chemistry, *Vol. 1, Nos. 1–2. Pp. 176. Pergamon Press Ltd., London.* 1957. *Subscription per volume, £6; for subscribers certifying that the journal is for their own personal use, £3 10s.* net.

Sir Robert Robinson, the founder of this new journal, writes in the foreword: 'The special character claimed for *Tetrahedron* is its fully international scope, since the new journal is envisaged as a forum for the presentation of original memoirs on organic chemistry contributed from all parts of the world.'

The composition of the Board of Honorary Regional Editors shows the international character: Professor M. S. Kharasch (Chicago), Professor R. H. Martin (Brussels), Professor A. N. Nesmeyanov (Moscow), Professor F. Weygand (West Berlin). The Executive Editor is Professor H. Stephen (London). The Honorary Editorial Advisory Board comprises 41 organic chemists from Europe, the American continent, and the Far East.

An international journal on organic chemistry with articles in English, German, and French will fill a gap. It provides the organic chemist with a forum which other sections of chemistry have already at their disposal in international periodicals.

'Tetrahedron' accepts not only original papers of the usual type, but also 'longer papers in which the results of extended investigations are described in a unified manner'. This first issue contains summarizing articles by G. Fodor, A. P. Terentiev and V. M. Potapov, P. J. C. Fierens and S. Berkovitch, and A. N. Nesmeyanov and others. It also includes 15 contributions, mainly on synthetic investigations of substances like alicyclic compounds, steroids, heterocyclic compounds, and alkaloids. J. P. WIBAUT

PRACTICAL FOSSIL CLASSIFICATION

Détermination pratique des fossiles, *by A. Chavan and A. Cailleux. Pp. 387. Masson et Cie, Paris.* 1957. *Paper covers, Fcs* 5000; *bound, Fcs* 5800 *net.*

About 100 years ago Bentham, in his 'Handbook of the British Flora' devised artificial keys for the naming of plants. They comprise a series of two (rarely more) alternatives as nearly as possible contradictory. Having determined which of the first alternatives fits the specimen, the inquirer is referred to another pair of alternatives, and so the sequence proceeds by dichotomy until eventually sufficient alternatives have been worked through to lead to a single generic name.

The authors have attempted a similar scheme for fossils, both animal and plant, and their plea is that palaeontology nowadays demands so much specialized knowledge that the amateur requires an easier method of identifying his fossils than labouring through large monographs. Like Bentham's analytical keys, those devised for fossils call for no more than a rudimentary understanding of morphology; the approach to the subject is mechanical, but possibly useful to those who look on fossils merely as objects showing infinite variety of form. There is no opportunity to evaluate relationships, no attempt to make a fossil 'live', no appreciation of its position in an evolutionary series, and no assessment of its value as an index to geological age, although the geological range is usually given. In fact, the book has little on those subjects for which many amateurs show the keenest curiosity and interest.

W. F. WHITTARD

EXTRACTS FROM DARWIN'S WORKS

The Darwin Reader, *edited by Marston Bates and Philip S. Humphrey. Pp. ix + 481. Macmillan & Co. Ltd., London.* 1957. *30s. net.*

It is undoubtedly extremely desirable that not only students of science but also the majority of well-educated persons should be acquainted with some of the classical scientific writings which have formed our present-day mode of envisaging the world we live in. However, this laudable aim is not very easy to achieve. How much time can most people spend in reading quite lengthy works, many of whose details may have been superseded, even though their main conclusions have grown in importance? Darwin is so much the focus of perhaps the most revolutionary change in 'common sense' that science has ever brought about that it is he, above all others, whom one would wish to see widely read. One can therefore be most grateful to Professors Bates and Humphrey, of the University of Michigan, for their admirable selection from his voluminous writings. Their extracts are introduced by some 100 pages from his Autobiography and 'The Voyage of the *Beagle*.' The 'Origin of Species', reduced to about a third of its full length, is prefaced by the Darwin-Wallace essays published by the Linnean Society; and the book concludes with selections from 'The Descent of Man', 'The Expression of the Emotions', and short extracts from the papers on climbing and insectivorous plants, and on the activities of earthworms. There is a short selected bibliography and an adequate index. C. H. WADDINGTON

THE NATURE OF A SPECIES

The Species Problem, *edited by Ernst Mayr. Pp. ix + 395. American Association for the Advancement of Science, Washington; Bailey Bros and Swinfen Ltd., London.* 1957. *80s. net.*

Nearly a century ago Darwin and Wallace showed that species arise by evolution, but uncertainty still reigns as to how a species should be defined. In the past, taxonomists have relied mostly on the morphological criterion of a group of organisms that resemble one another more closely than they resemble any other organisms. This criterion is often the only one that can be practically applied, particularly on preserved material and fossil specimens. It suffers from the criticism that the amount of morphological difference that entitles a population to the status of a species is an arbitrary decision of the taxonomist.

The biological concept of the species is free from this criticism, for it considers the species as a group of organisms prevented from reproducing with other organisms by fertility barriers which may be ecological, genetical, or geographical, and can be tested and settled by observation and experiments on living populations in nature; but this criterion is difficult to apply to organisms that reproduce asexually, and to fossils. Yet another concept of the species is as a 'gene-pool' of such a kind that an hereditary character of any individual can potentially be transmitted to any other individual of a later generation, in any part of its geographical range.

These remarks will suffice to show that there is such a thing as the 'species problem', and that it is very important. Dr Ernst Mayr is universally recognized as a leading authority on these problems, and this work should be accessible in all scientific institutions where they are taught and investigated.

GAVIN DE BEER

BIOCHEMICAL ANALYSIS

Methods of Biochemical Analysis, *Vol. V, edited by David Glick. Pp. ix + 502. Interscience Publishers Inc., New York; Interscience Publishers Ltd., London.* 1957. $9.50 *net.*

Biochemical techniques of analysis are of ever-increasing complexity and are being developed at a very rapid rate. It is therefore useful to have this annual series, now in its fifth year, which presents monographs on procedures for the determination of biologically important substances. The present volume of eight contributions deals with the assay of cholinesterase (K. B. Augustinsson); biological (i.e. antibiotic, hormonal, enzymic, pharmacological and immunological) standards in biochemical analysis (J. H. Humphrey, D. A. Long and W. L. M. Perry); α-keto acid determination (W. J. P. Neish); microdetermination of cobalt (B. E. Salzman and R. G. Keenan); activation analysis ('activation analysis' rests on the fact that many elements may be determined in minute quantities by measuring the radioactivity induced when the sample is exposed to bombardment by nuclear particles) in biochemistry (B. A. Loveridge and A. A. Smales); contamination in trace element analysis and its control (R. E. Thiers); chemical determinations of oestrogens in human urine (W. S. Bauld and R. M. Greenway); infra-red analysis of vitamins, hormones, and coenzymes (H. Rosenkrantz). The monographs are detailed and competent. They give adequate working instructions together with critical comments and extensive references to the literature. The volume is a very valuable addition to the reference books on modern biochemical techniques.

H. A. KREBS

TEXTBOOK OF ZOOLOGY

Précis de biologie animale, *by M. Aron and P.-P. Grassé. Pp. viii + 1413. Masson et Cie, Paris.* 1957. *Paper covers, Fcs* 5300 *net; bound, Fcs* 5900 *net.*

This book is designed to meet the requirements in biology of French students working for the certificate in chemistry, physics, and biology, a standard which they must successfully attain at their university before they can start their studies in medicine, pharmacy, or dentistry. This certificate, which now involves a new syllabus, corresponds, therefore, to the British First M.B. examination, and it is interesting to compare this book with its British equivalents. Here it need only be said that this book would form an admirable handbook for an honours course in zoology. Of particular interest are the space and treatment given to such subjects as viruses, genetics, cellular permeability, the chemistry of respiration, enzymes, hormones, dietetics, nervous excitation, and evolution. The portion of the book devoted to the structure and development of the various groups occupies 624 pages, less than half the total. Seldom has so much reliable and up to date information been contained in one handy and attractive volume. Its price, however, equivalent to about £5, makes it difficult to see how students can hope to possess their own copies.

GAVIN DE BEER

HISTORY OF THE PHYSIOLOGY OF PAIN

Anatomies of Pain, *by K. D. Keele. Pp. x + 206. Blackwell Scientific Publications, Oxford.* 1957. 27*s. net.*

Dr Keele endeavours to persuade us in the first half of his book that those who are now concerned with the study of the physiology of pain would benefit substantially by considering a review of what has been said on this subject from the earliest times.

My own belief is that, fascinating as the study of the history of physiology before the nineteenth century may be, it contains nothing of the slightest use to modern physiologists, and Dr Keele's book only serves to strengthen me in this conviction. What the ancients might have to say about their subjective experiences of physical pain would still be of interest, but if any such records exist, Dr Keele does not seem to have found them. This is not said to impugn his industry, which has been beyond praise: but in dealing with ancient authors, industry is not enough.

The second half of Dr Keele's book, which reviews studies of pain since about 1800, is undoubtedly of relevance to present work, and had the first half been omitted the author could have expanded and improved to great advantage what remained.

J. S. WILKIE

AGRICULTURAL ECONOMY

Types of Rural Economy. Studies in World Agriculture, *by R. Dumont. Pp. xii + 556. Methuen & Co. Ltd., London.* 1957. 45*s. net.*

This is a very good English translation of a long and detailed work by a professor of agricultural economy in the University of Paris. It consists of a series of case studies of individual farms and local agricultural areas in different parts of the world, from the Belgian Congo in the south to England in the north, and across as far as northern Vietnam in the east. These cases, not necessarily typical or average, but which arose from the author's personal experience, are used to illustrate what the author considers to be the major agricultural problems of large areas of the world. They are used, in particular, to contrast the problems of backward and poor farms as against progressive holdings and constructive national agricultural policies. Out of this come, for example, appreciative comments on recent English farm policy and strong criticism of French farming practice.

The value and strength of the book lie in the pen portraits of individual farms across the world, drawn in terms of the ways in which the farmers actually live. This will be particularly valuable to students of agriculture in countries where there is little local agricultural literature, for example those studying in the new University Colleges in Africa. A possible weakness of the book lies in the matrix of general argument into which the chunks of detail are embedded. This argument is somewhat long-winded and interspersed with factual information which does not always give clarity. The author certainly emphasizes important basic problems and their recurrence among countries. These problems include those of smallness of farm businesses, the extensive use of good land, the over-intensive use of poor land, the benefits of farm mechanization, the effects of population pressure on rural land use, and the poverty and weakness of heavily agrarian countries or regions. Yet how fascinating it is to have these problems discussed by a Frenchman rather than by a Briton or American.

G. P. WIBBERLEY

PEST CONTROL

Advances in Pest Control Research, *Vol. I, edited by R. L. Metcalf. Pp. vii + 514. Interscience Publishers Inc., New York; Interscience Publishers Ltd., London.* 1957. $11 *net.*

Few fields of human endeavour embrace such a range and depth of the scientific disciplines as that of controlling our fungal, weed, insect, and other biological rivals. The first volume of the new series 'Advances in Pest Control Research', edited by Dr Metcalf, is therefore very welcome and fulfils a real

need. In relation to insect control this need has been partly met by the new 'Annual Review of Entomology', and it is hoped, therefore, that the slight danger of wasteful overlapping in this area will not be overlooked by the respective editors of future volumes of both series.

The first volume of 'Advances' deals with the following subjects: Health hazards associated with chemical pesticides, herbicidal action, fungicidal action, organophosphorus insecticidal action, control of soil fungi, use of systemic insecticides, development and application of insect repellants, chemical and biological assay of pesticide residues, and the use of radioisotopes in pesticide research. Without exception the contributors are recognized authorities within their fields. Unfortunately their clarity and style of writing are sometimes unsatisfactory. Thus the definition of a systemic insecticide (pp. 305–6) is more of a confusion than a definition; the frivolous style of one contributor may irritate the reader who finds such remarks as 'I shall have fun being unorthodox again' (p. 199) a little misplaced in a scientific review; while the use of coined terms, strange expressions such as 'enzymatic metabolization' (p. 308), or unexplained and ambiguous abbreviations such as 'IAA' (p. 59) may also displease the reader. Despite these blemishes the book contains a wealth of useful information and, in parts, provides stimulating reading. This first volume and the succeeding volumes should find space on the shelves of all those concerned with pesticide research and development.

F. P. W. WINTERINGHAM

TREES IN INDIA

Flowering Trees in India, *by M. S. Randhawa. Pp.* 210. *Indian Council of Agricultural Research, New Delhi.* 1957. 15 *rupees net.*

The mere title of this book, written by Dr Randhawa, Vice-President of the Indian Council of Agricultural Research, gives no hint of the wealth of information that is contained between its covers. It consists of a series of well-written essays on such diverse topics as trees as artistic subjects, folklore of trees, plant migration, landscape planning, *Vana Mahotsava* or the Indian National Festival of Trees, trees for towns, main roads, the garden, and much more besides. The book is lavishly illustrated by coloured plates, some of which are excellent; others can be appreciated only by those who possess an artistic soul, a gift which the reviewer unfortunately lacks.

The man who stands revealed in this book is that unusual combination of idealist and hard-headed pragmatist, one who can see the wood as well as the trees. India is lucky to have him.

N. L. BOR

HISTORY OF SCIENCE

Histoire des sciences, *by Fernand Perrin. Pp.* 605. *Editions Beaudart, Paris.* 1957. *Fcs.* 4315 *net.*

It is improbable that this history can replace the variety of works in English that describe in outline either the whole evolution of science or that occurring in a limited period. It is in fact little more than a collection of short scientific biographies, and a record of discoveries presented without logical coherence. What is one to make of a history of science that not only ignores all its branches save mathematics, astronomy, and physics in the early stages, but devotes more space to Virgil and Cyrano de Bergerac than to Aristotle and Galileo? Again, there are separate chapter headings for Rabelais and Montaigne—worthies indeed, but hardly major figures in the growth of science —while Vesalius is mentioned (with Servetus, and misleadingly at that) in 3½ lines. The medieval section in this book is poor, but the way in which the history of science in classical and early modern times is treated is hardly better.

The later sections are more useful, if only because more detailed—nearly half the volume is devoted to the present century. They have the virtue of making clear the difficulties that have to be overcome before a history, rather than a chronicle, of modern science can be written, difficulties that the author fails to surmount. It seems a pity that the vast labour of compilation devoted to this volume should have so little value as history. Has all the effort of the last fifty years to advance the study of the history of science in scholarship and intellectual standing been in vain? One cannot believe this: yet little of that effort is reflected in the structure and content of M. Perrin's history.

A. R. HALL

LIGHT WITHOUT HEAT

A History of Luminescence from the Earliest Times until 1900, *by E. Newton Harvey. Pp.* xxiii + 692. *The American Philosophical Society, Philadelphia.* 1957. $6 *net.*

Within the space of a brief review it is impossible to do justice to this remarkable book, where the history of luminescence from ancient China and Japan to the close of the nineteenth century is described with a wealth of references to original authorities: the select bibliography alone runs to 69 pages of small type. The study of luminescence has in fact been the life work of Professor Newton Harvey, primarily as regards the production of light by luminous organisms but not neglecting inorganic sources. Though the phenomena themselves have always exerted a peculiar fascination on the human mind, they are so varied that their investigation involves the application of many different branches of science, and it is not surprising that the origin of many natural weak lights remained a mystery until comparatively recent times.

In the present book the author offers first a general survey of the increasing knowledge of luminescences and then deals with the special types of luminescence associated with the non-living and the living world respectively. Among the non-living types are electroluminescence, phosphorescence, thermoluminescence, triboluminescence, fluorescence, radioluminescence, and chemiluminescence, while under the general heading of bioluminescence come the shining of fish, flesh, and wood, the phosphorescence of the sea, and animal luminescence. Here we find such curious information as that, in 1782, Russian midges became infected with bacteria that gave them a fatal disease that made them luminous; that Spallanzani crushed two large medusae in thirteen ounces of water until no more light appeared and so obtained 'an artificial phosphor' which shone when heated to 30° Réaumur; and that in 1790 decaying potatoes in a barracks at Strasbourg gave off enough light to read by.

Lest these examples convey the impression that the book is merely a collection of *curiosa*, it should be emphasized that the atmosphere throughout is strictly scientific, the section on bioluminescence—a subject to which Professor Newton Harvey has made many important original contributions—being particularly valuable. The folklore concerning the glow-worm and firefly is being prepared for a later volume—in which English readers will also hope to find an account of the natural history of 'The Dong with a Luminous Nose'!

E. J. HOLMYARD

HISTORY OF CHEMISTRY

Through Alchemy to Chemistry, *by John Read. Pp.* xvii + 206. *G. Bell & Sons Ltd., London.* 1957. 18*s.* 6*d. net.*

To Professor Read 'Chemistry is the most romantic of all the branches of science'; it is the culmination of a long and variegated history. Undismayed by the magnitude of his task, he has taken as his subject the whole field of that history and he here presents it to the general reader within the confines of one small book. Much has had to be sacrificed in the process: but there has also been gain. He seeks to counter the over-specialized outlook of contemporary scientific research by stimulating interest in 'the broad humanistic aspects of science', and his survey of alchemical traditions shows that the gradual emergence of modern chemistry, as we know it today, is a positive and experimental expression of what had for centuries been a speculative pursuit of philosophers and craftsmen.

The chapters on the beginnings of alchemy in the ancient world are of especial interest. Professor Read is at his best when he discusses the mythological interpretation of alchemical ideas in the seventeenth century that centred around the person of Michael Maier, and the part played by the pseudo-alchemists. The latter is of prime importance in the matter of a just appraisal of the hundreds of alchemical texts.

There are a glossary and many reproductions of old illustrations, chosen with considerable care. G. HEYM

HISTORY OF TECHNOLOGY

A History of Technology, *Vol. III.* From the Renaissance to the Industrial Revolution, *c.*1500–*c.*1750, *edited by Charles Singer, E. J. Holmyard, A. R. Hall, and Trevor I. Williams. Pp. xxxvii* + 766. *Clarendon Press, Oxford.* 1957. £8 8*s. net.*

The third volume of this unique contribution to the history of technology is devoted mainly to the years between the Italian Renaissance and the Industrial Revolution, that is approximately 1500–1750. Like its predecessors, it contains a number of chapters dealing with the various branches of technology, each written by a specialist who can speak with authority. In spite of the compression needed to cover the whole field within a reasonable compass of 760 pages, each account is comprehensive, clear, and free from technicalities. The chapters are grouped under the headings of primary production, manufacture, material civilization, communications, and the approach to science. Between them they cover very completely the progress of technology during the centuries when the germs of the evolution of our modern scientific and industrial civilization were first becoming clearly visible.

Unlike the preceding volumes, this one deals exclusively with advances in the West, for the years in question were those that saw the rise of its dominance over the East, with the birth of modern science and of the machine age based on coal and iron. It was a fascinating age of progress, of great inventiveness, and of constant effort. Technology was changing the economic and social pattern of Europe, awaiting only the stimulus of the steam engine for the great industrial expansion of the West. Science was just beginning to contribute to some techniques, for instance navigation, but on the whole science owed more to technology than technology did to science. That had to wait until scientific theory had found a surer basis. The prime mover in this development was invention, stimulated by the growing needs of the Western nations with their restless energy that marked these centuries.

It is impossible in this short review to do justice to the range, the quality, and the interest of each chapter, in which a wealth of illustrations does much to bring their stories to life. Each reader will have his own preferences: I enjoyed particularly the chapters on printing by Michael Clapham, and on precision and scientific instruments by Derek Price.

Suffice it to say that this volume more than maintains the standard of the first two, thanks to the care and skill of the editors. One's only regret is that the high price of the book, in spite of the generous subscription by Imperial Chemical Industries, will inevitably limit the number of bookshelves on which it will find a most welcome and valuable place. HAROLD HARTLEY

HISTORY OF IRON AND STEEL

History of the British Iron and Steel Industry from *c.* 450 B.C. to A.D. 1775, *by H. R. Schubert. Pp. xxi* + 445. *Routledge and Kegan Paul, London.* 1957. 60*s. net.*

The high expectations raised by Dr Schubert's short notes in the 'Journal of the Iron and Steel Institute' are fully met by this more complete work. The author begins by analysing the archaeological evidence on the first production of iron in the British Isles. He then traces the subsequent regional distribution of the industry and changes in methods of working, from the primitive bowl furnace through the displacement of the direct process by the blast furnace and finery. He treats the introduction of coke very briefly, and his terminal date excludes consideration of the new epoch started by Cort's puddling process and the introduction of steam power. The book is well illustrated and has important appendices summarizing statistical data and giving *in extenso* the text of some seventeenth and eighteenth century records and descriptions.

The book will be particularly valuable to the economic historian, for the new documentary sources that the author has found in public and private archives indicating the magnitude of the industry at various places and times present a much more complete picture than was previously available. Such sources are less satisfactory for answering technical questions about processes. Dr Schubert's discovery of the unfinished manuscript of William Lewis's six-volume 'Chemical and Metallurgical History of Iron' is important, for this is the first treatise on iron written in English by a man of scientific stature. At best, however, the siderurgical literature of Britain is sparse, and one wishes that the nationalistic restriction had been relaxed to allow the author to make more extensive use of the richer Continental published material. Of course, such technical literature is often misleading, for literary ambitions are rarely joined with practical knowledge, and this is more than usually true with ferrous metallurgists.

The lack of such a background of English technical source material affects particularly the sections of the book dealing with steel.

Altogether, however, this is a fascinating story of iron and of the waves of technological improvement that have successively changed its nature and importance. There are few of man's activities that have involved so fine an interplay between a knowledge of the properties of materials and skill in the organization of men. Dr Schubert's nose for new sources of information and his ability to analyse and present it in an interesting way makes this a most important book. Both historians and metallurgists will be grateful to him, and to the Iron and Steel Institute whose support made the work possible.

CYRIL S. SMITH

Short notices of books

(These notices are descriptive rather than critical and are designed to give a general indication of the nature and scope of the books.)

Elements of Heat Transfer (*third edition*), *by M. Jakob and G. A. Hawkins. Pp. xxv + 317. John Wiley & Sons Inc., New York; Chapman and Hall Ltd., London.* 1957. 54*s. net.*

The two previous editions of this book were titled 'Elements of Heat Transfer and Insulation' and were students' textbooks of heat transfer. The original edition was deliberately confined to fundamentals; the present volume has continued the process, initiated by the second edition, of adding more difficult methods and details.

The chapter on thermal conductivity now includes a table on the thermal conductivity of liquid metals. Other additions include the use of equivalent circuits for the solution of heat transfer problems, and one type of thermal analyser. There are new sections added to the chapters on heat transfer by forced convection, and by combined conduction and convection. A new chapter on mass transfer has been added, and a section introducing the student to the important subject of gas radiation. The references have been brought up to date, and more problems are included.

The Proceedings of the Third International Conference on Electron Microscopy, held in London 1954, *edited by R. Ross. Pp. xvi + 705. Royal Microscopical Society, London.* 1956. 90*s. net.*

The 158 papers read at this important international conference most comprehensively cover the whole field of electron microscopy. They consider, for example, the design of instruments and the finished apparatus; the effect of electrons on the specimens; metallurgical applications; viruses and bacteria; interference and phase effects; internal structure of cells; replica methods; and the operation of electron microscopes. The whole collection forms a valuable work of reference.

The Planet Earth, *edited by D. R. Bates. Pp. 312. Pergamon Press Ltd., London.* 1957. 35*s. net.*

The intelligent layman is the intended reader of this introduction to the background of the International Geophysical Year. Geophysics is completely covered, and each chapter is written by an authority.

The subjects include the nature of the Earth, the oceans, and the atmosphere, the origins of the Earth and of life, and the possible fate of the Earth. There is a selected bibliography giving further reading for each section.

The Planning of International Meetings. A C.I.O.M.S. Handbook. *Pp. 113. Blackwell Scientific Publications, Oxford.* 1957. 7*s.* 6*d. net.*

UNESCO and WHO jointly established the Council for International Organizations of Medical Sciences, which was founded in 1949 and has aimed at raising the standard of international medical meetings and at coordinating congresses. The book discusses all types of conference, from the large international congress to the committee, and covers all aspects, from preliminary organization to publication of the journals and proceedings of the congress and its evolution. Separate sections deal with the solution of language problems, relation of the organizers with participants, and social events. Appendices give specimen application forms for visitors and participants and specimen guides to contributors.

Pioneering in Industrial Research. The Story of the General Electric Research Laboratory, *by K. Birr. Pp. vii + 204. Public Affairs Press, Washington, D.C.* 1957. $4.50 *net.*

Dr Birr's history of the General Electric Research Laboratory is a detailed study of the laboratory's organization, administration, and accomplishments.

It opens with a general history of industrial research, continues with a short outline of the early history of the companies that formed the General Electric Company, and then covers the history of the General Electric Research Laboratory from its foundation in 1901 under its first director, Willis R. Whitney. The research mentioned starts with work on the electric bulb, and the story is continued to the recent production of artificial diamonds. The book is by an historian and does not contain details of technical processes.

Ciba Foundation Colloquia on Endocrinology. *Vol. XI,* Hormones in Blood, *edited by G. E. W. Wolstenholme and Elaine C. P. Millar. Pp. vi + 416. J. and A. Churchill Ltd., London.* 1957. 56*s. net.*

The four-day colloquium 'Hormones in Blood' reported in this volume was organized by the Ciba Foundation in February 1957. All the papers emphasize the study of the hormones in the blood as opposed to their study when excreted in the urine. The twenty-one papers together with the discussion on them published here give a very complete view of the present state of knowledge of physiologists, biochemists, biologists, and endocrinologists in this field, and outline the trends of present-day research into the major problems.

Hides, Skins and Leather under the Microscope. *Pp. 368. The British Leather Manufacturers' Research Association, Egham, Surrey.* 1957. £8 10*s. net.*

After thirty-five years' work the British Leather Manufacturers' Research Association possesses over 30,000 photomicrographs, a collection unparalleled elsewhere. Nearly a thousand are reproduced in this book, illustrating the structure of a wide range of hides, finished leathers, damaged or diseased material, and so on. Each illustration has a detailed explanatory caption. This is a very comprehensive work of reference.

The Chemistry of Natural Products. *Vol. I.* The Alkaloids, *by K. W. Bentley. Pp. vii + 237. Interscience Publishers Inc., New York; Interscience Publishers Ltd., London.* 1957. $4 *net.*

The important facts about the structural chemistry of the more important alkaloids, and the degradation and synthetic means by which these structures were elucidated are covered by this book. It is directed at the undergraduate student with a view to extending the limited treatment of the subject in the general textbooks without attempting specialized detail. Alternate pages are wholly devoted to formulae with a view to making the subject more easily understandable.

Notes on contributors

SIR GAVIN DE BEER,
M.A., D.Sc., D. ès L. (Lausanne), F.R.S.,

Was born in 1899 and educated at the *Ecole Pascal*, Paris, at Harrow School, and at Magdalen College, Oxford. He was a Prize Fellow of Merton College, Oxford, 1923–38, and Senior Demonstrator in Zoology, University of Oxford, 1926–38. In the second World War he served as a lieutenant-colonel in the Grenadier Guards in command of psychological warfare in 21 Army Group. He has been Director of the British Museum (Natural History) since 1950. He will be president of the 15th International Congress of Zoology, which will meet in London in July this year.

N. P. INGLIS,
Ph.D., M.Eng., M.I.Mech.E., F.I.M.,

Was born in 1902 and was educated at the Liverpool Collegiate School and the Universities of Liverpool and Illinois. He joined Synthetic Ammonia and Nitrates Ltd. (now the Billingham Division of Imperial Chemical Industries Ltd.) in 1927 as a metallurgist, and in that capacity carried out research and development on metals suitable for what were then novel chemical processes, including in particular work on the influence on steels of hydrogen at elevated pressures and temperatures, and also on problems connected with the use of corrosion-resistant steels. He was appointed a director of the Metals Division of I.C.I. in 1947 and its Research Director in 1951. He is a vice-president of the Institute of Metals.

M. K. McQUILLAN,
M.A.,

Was born in 1921 and went to Cambridge in 1939. She joined the Metallurgy Division at the Royal Aircraft Establishment on graduation in 1942, and shortly afterwards became a member of a newly formed group established to work on materials suitable for jet-propelled aircraft. Her active interest in titanium dates from this time, and continued while she was at the Aeronautical Research Laboratories, Melbourne, and at the Metals Division of Imperial Chemical Industries Ltd. In 1946–47 she was one of a group from the Royal Aircraft Establishment which formed the nucleus of the Metallurgy Division at the Atomic Energy Research Establishment, Harwell. With her husband, Professor A. D. McQuillan, she has published 'Titanium', a book on the metallurgy of the metal.

H. S. W. MASSEY,
B.A., M.Sc., Ph.D., F.R.S.,

Was born in 1908 and was educated at the University High School, Melbourne, and Melbourne University. After graduation he undertook research work in atomic physics at the Cavendish Laboratory, Cambridge. In 1933 he was appointed head of the department of mathematical physics at Queen's University, Belfast, and in 1938 became Goldsmid professor of mathematics at University College, London. He held this chair until 1950, when he became Quain professor and head of the department of physics at the same college. In addition to many papers and reviews in scientific journals he is joint author of two monographs, 'The Theory of Atomic Collisions' (with N. F. Mott) and 'Electronic and Ionic Impact Phenomena' (with E. H. S. Burhop); he has written three other books, 'Ancillary Mathematics', 'Atoms and Energy', and 'Negative Ions'.

W. O. JAMES,
M.A., D.Phil., F.R.S.,

Was born in London in 1900 and was educated at Tottenham Grammar School and the Universities of Reading and Cambridge. He worked first at Rothamsted on the potassium nutrition of plants. He is Reader in Botany in the University of Oxford, and since 1927 has led a school of teaching and research in plant physiology, especially concerned with nutrition and respiration. During the war and after he was Director of the Oxford Medicinal Plants Scheme, dealing with the production of drug plants in Britain and with the study of alkaloid metabolism in the *Solanaceae*. He is an editor of the 'New Phytologist', and has published 'The Biology of Flowers' (with A. R. Clapham), 'Plant Respiration', some well-known textbooks, and numerous papers in several branches of botany.

ABDUS SALAM,
M.A., Ph.D., D.Sc.,

Was educated at the Universities of the Punjab and Cambridge. He was elected to a research fellowship of St. John's College, Cambridge, in 1951 and was appointed Professor of Mathematics at Government College, Lahore, in the same year. He became Head of the Department of Mathematics in the University of the Punjab in 1952 and a lecturer in the University of Cambridge in 1954. In 1955 he was Scientific Secretary at the Geneva conference on the peaceful uses of atomic energy. He has been Professor of Applied Mathematics at Imperial College, London, since 1957. His work has been in theoretical physics, particularly in the development of quantum electrodynamics and of theories interpreting the properties of mesons and other recently discovered fundamental particles.

Some books received

(*Note.* Mention of a book on this page does not preclude subsequent review.)

AGRICULTURE

Atomic Energy and Agriculture, *by C. L. Comar. Pp. x + 450. American Association for the Advancement of Science, Washington, D.C.; Bailey Bros. and Swinfen Ltd., London.* 1957. 86*s. net.*

The Forest Area of the World and its Potential Productivity, *by Sten Sture Paterson. Pp.* 216. *The Royal University, Gothenburg.* 1956. *Sw. Kr.* 58 *net.*

BIOCHEMISTRY

Advances in Enzymology, *Vol. XIX, edited by F. F. Nord. Pp. v + 457. Interscience Publishers Inc., New York; Interscience Publishers Ltd., London.* 1957. $9.85 *net.*

BIOGRAPHY

Biographical Memoirs of Fellows of the Royal Society, *Vol. III. Pp.* 328. *The Royal Society, London.* 1957. 30*s. net.*

BIOLOGY

Cell Physiology, *by A. C. Giese. Pp. xviii + 534. W. B. Saunders Co., London.* 1957. 70*s. net.*

The Strategy of the Genes, *by C. H. Waddington. Pp. ix + 262. George Allen and Unwin Ltd., London.* 1958. 28*s. net.*

CHEMISTRY

Advances in Catalysis and Related Subjects, *Vol. IX:* Proceedings of the International Congress on Catalysis, held in Philadelphia, Pennsylvania, September 10–14, 1956, *edited by D. D. Eley, W. G. Frankenburg, and V. I. Komarewsky; Special Editor for Vol. IX, A. Farkas. Pp. xviii + 847. Academic Press Inc., New York.* 1957. $16 *net.*

The Chemistry of the Steroids, *by W. Klyne. Pp.* 216. *Methuen & Co. Ltd., London.* 1957. 18*s. net.*

Contributi Teorici e Sperimentali di Polarografia, *Vol. III. Pp.* 567. *Consiglio Nazionale delle Ricerche, Rome.* 1957. 4500 *lire net.*

Handbook of Chemistry and Physics, *edited by C. D. Hodgman, R. C. Weast, and S. M. Selby. Pp. xxii + 3213. Chemical Rubber Publishing Co., Cleveland, Ohio.* 1957.

Idrologia, *by Giuseppe Bragagnolo. Pp. xv + 507. Published on behalf of the Terme di Boario, Milan.* 1957. 2000 *lire net.*

Nouveau traité de chimie minérale, *edited by Paul Pascal, Vol. III. Pp. xii + 838. Masson et Cie., Paris.* 1957. *Paper covers, Fcs.* 6000 *net; bound, Fcs.* 6900 *net.*

Quantitative Organic Analysis, *by J. S. Fritz and G. S. Hammond. Pp. ix + 303. John Wiley & Sons Inc., New York; Chapman and Hall Ltd., London.* 1957. 52*s. net.*

Solvent Extraction in Analytical Chemistry, *by G. H. Morrison and H. Freiser. Pp. xi + 269. John Wiley & Sons Inc., New York; Chapman and Hall Ltd., London.* 1957. 54*s. net.*

Tracer Applications for the Study of Organic Reactions, *by John G. Burr, Jr. Pp. x + 291. Interscience Publishers Inc., New York; Interscience Publishers Ltd., London.* 1957. $7.50 *net.*

Volumetric Analysis, *Vol. III,* Titration Methods: Oxidation-Reduction Reactions, *by I. M. Kolthoff and R. Belcher, with the co-operation of V. A. Stenger and G. Matsuyama. Pp. ix + 714. Interscience Publishers Inc., New York; Interscience Publishers Ltd., London.* 1957. $15 *net.*

GENERAL SCIENCE

Ergonomics—Human Factors in Work, Machine Control and Equipment Design, *Vol. I, No. I, General Editor, A. T. Welford. Pp.* 100. *Taylor and Francis Ltd., London.* 1957. 25*s. net.*

MATHEMATICS

Digital Differential Analyzers, *by George F. Forbes. Pp.* 154. *G. F. Forbes, Pacoima, California.* 1957. $5 *net.*

MEDICINE

Anales del Instituto de Farmacologia Española, *Vol. V, by Herbert S. Gasser. Pp.* 520. *Fundación Marqués de Urquijo, Madrid.* 1956.

The Diagnosis and Treatment of Infections, *by D. Geraint James. Pp. viii + 234. Blackwell Scientific Publications, Oxford.* 1957. 30*s. net.*

Documenta Ophthalmologica, *Vol. XI, edited by G. von Bahr, J. ten Doesschate, H. Fischer von Bünau, J. François, H. Goldmann, G. Lo Cascio, H. K. Müller, Jean Nordmann, A. F. Schaeffer, and Arnold Sorsby. Pp.* 334. *Dr W. Junk, The Hague.* 1957. *Fl* 80 *net.*

Drug Resistance in Micro-Organisms—Mechanisms of Development (A Ciba Foundation Symposium), *edited by G. E. W. Wolstenholme and Cecilia M. O'Connor. Pp. xii + 352. J. and A. Churchill Ltd., London.* 1957. 50*s. net.*

Forschungen und Forscher der Tiroler Ärzteschule (1951–1953), *Vol. III. Pp.* 429. *Medizinische Fakultät der Universität, Innsbruck.* 1957.

General Pathology (*second edition*), *edited by Sir Howard Florey. Pp. xv + 932. Lloyd-Luke (Medical Books) Ltd., London.* 1957. 84*s. net.*

La psychanalyse et les ulcères gastroduodénaux, *by Angel Garma, translated from the Spanish by W. and M. Baranger. Pp. viii + 178. Presses Universitaires de France, Paris.* 1957. *Fcs.* 700 *net.*

PHYSICS

Fundamental Constants of Physics, *Vol. I, by E. Richard Cohen, K. M. Crowe and J. W. M. Dumond. Pp. xii + 287. Interscience Publishers Inc., New York; Interscience Publishers Ltd., London.* 1957. $7.50 *net.*

High Energy Nuclear Physics. Proceedings of the Seventh Annual Rochester Conference, April 15–19, 1957, *edited by G. Ascoli, G. Feldman, L. J. Koester, Jr., R. Newton, W. Riesenfeld, M. Ross, and R. G. Sachs. Pp. ix + 482. Interscience Publishers Inc., New York; Interscience Publishers Ltd., London.* 1957. $4.50 *net.*

Magnetohydrodynamics, *edited by R. K. M. Landshoff. Pp. viii + 115. Stanford University Press (Oxford University Press, London.* 1957. 32*s. net.*

Radiation Effects in Solids, *Vol. II, by G. J. Dienes and G. H. Vineyard. Pp. viii + 226. Interscience Publishers Inc., New York; Interscience Publishers Ltd., London.* 1957. $6.50 *net.*

Les grands problèmes des sciences, *Vol. VIII.* Théorie synthétique de la relativité restreinte et des quanta, *by O. Costa de Beauregard. Pp. xii + 200. Gauthier-Villars, Paris.* 1957. *Fcs.* 3800 *net.*

ZOOLOGY

Insect Flight, *by J. W. S. Pringle. Pp. viii + 132. Cambridge University Press, London.* 1957. 15*s. net.*

Traité de paléontologie. *Vol. VII.* Primates: paléontologie humaine, *by Jean Piveteau. Pp.* 675. *Masson et Cie, Paris.* 1957. *Paper covers, Fcs.* 12 000 *net; bound, Fcs.* 12 800 *net.*

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